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BULLETIN OF THE DEPARTMENT OF GEOLOGY

ANDREW C. LAWSON
EDITOR

VOLUME 4
WITH 51 PLATES

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UNIVERSITY OF CALIFORNIA PUBLICATIONS
BULLETIN OF THE DEPARTMENT OF
GEOLOGY

Vol. 4, No. 1, pp. 1-32, Pls. 1-4 ANDREW C. LAWSON, Editor

THE GEOLOGY OF THE UPPER REGION OF THE MAIN WALKER RIVER, NEVADA.

BY
DWIGHT T. SMITH.

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INTRODUCTION.

This region, which the writer has termed the Upper Region of the Main Walker, is situated between latitudes 39° 10′ and 38° 58′ 48″, and longitudes 119° and 119° 22′ W., in the western part of the Great Basin. It is thirty miles due east of Lake Tahoe, and twenty miles southeast in a direct line from the Comstock Lode of the famous Washoe District. It is seventy miles northwest of the Esmeralda Formation. To reach it one may go by railroad from Reno, Nevada, to Wabuska, a dinner station on the C. C. railroad, the distance from Reno being seventy-eight miles.

The earliest notice that this region received was by Fremont while on one of his explorations in search of a route to the Pacific Coast, and in later times it has been sought by the stockman, ruralist and miner. The river received its name from the great explorer who gave it in honor of Joseph Walker, a noted scout and guide; and while on the ridge through which the West Walker flows for the purpose of joining its confluent, the East Walker, he ventured an opinion concerning the character of the rocks composing the ridge.

The region has not, however, received special attention at the hands of any geologist. The mention it has received has been mainly cursory or in a subsidiary connection; and recently[1] as incidental to a reconnaissance of Nevada and part of California south of the fortieth parallel of latitude.

The region being somewhat removed from other fields that have been studied, its investigation has been undertaken in the hope of contributing some independent observations to the geological history of the Great Basin, of which it forms a small part.

The rock series of the Upper Main Walker fall naturally into two major divisions corresponding to the Bedrock Complex and Superjacent Series of the Sierra Nevada.

The Bedrock Series comprises shales and limestones in a closely folded condition invaded by large intrusive masses of granite and granite porphyry and by dykes of quartz-porphyry and porphyrite. The Superjacent Series, reposing in unconformity upon the worn surface of the Bedrock Complex, comprises Tertiary sandstones and conglomerates together with an earlier and a later andesite, andesitic tuff and breccia, rhyolite and basalt. These Tertiary rocks have a prevailingly westward dip and are repeatedly monoclinal. Still later in age, lying horizontally upon these are beds which are questionably Quaternary or late Tertiary, and also formations of undoubtedly Quaternary age. The ridges bound areas that are rudely rectangular. Mineral veins are numerous, and several of these possess value.

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[1] Spurr, U.S.G.S. Bull. 208.

PHYSICAL FEATURES OF THE REGION.

The immediate area mapped is shown on the two accompanying plates, 1 and 2. The second is a continuation of the first at the southeast corner, and contains one ridge, Whirlwind Mountain. Pl. 1 contains three, two of which entirely cross the area; the other lies along the western border part way. Their trend is northerly and southerly, and between each are valleys having long alluvial slopes to the west; much shorter slopes come down to meet these slopes from the west, in which event they meet along a line, but in some instances they meet on a margin of a plain or playa. Where the meeting is along a line it may be readily recognized as an axis of drainage. These two features, the line and plain, may meet, and if the latter has a sufficiently low outlet the drainage line is continued toward the outlet. As the western slope of the alluvium is much the longer, so also is the slope above the alluvium toward the crest of the more or less bare rock. The eastern slope is much the steeper as well as the shorter.

The westernmost or first ridge is separated from the second[1] by a broad cañon which is rather too wide to be termed a cañon and may be designated a cañon-valley, and is known as Churchill Cañon. The northward extension of this valley is a cañon from the west. This cañon disconnects the first ridge at its northern end from a plateau or "benchland," a portion of which comes on the map Pl. 1 in the northeast corner. It also exposes several of the formations.

---

[1] Mr. C. H. Asbury of the Carson Indian School was very kind in endeavoring to obtain the Indian name of this ridge. Through Mr. R. C. Dyer, an interpreter, he ascertained that its name was Sing-ats'-e.

The second and third ridges are separated by a broad valley known as Mason Valley, of about ten miles width, and through it the river finds its course. Two streams, the East and West Walker, unite about two miles south of the country mapped in Pl. 1 in this same valley, and form the main river.

DISTRIBUTION OF FORMATIONS.

The First Ridge.—The "Benchland" in the northwest corner of the map is made up for the most part of andesite tuff and breccia, and is capped by a nearly level lying later andesite. The thickness of the cap is not uniformly the same, but the sections that were closely inspected were less than twenty feet. The andesite breccia in the tuff underlying the cap is entirely different from the cap, hornblende being a striking constituent. The tuff possesses occasionally some stratification. The erosion of the cañon has not cut entirely through the tuff, and an estimate of its thickness was not made. A few occasional springs make their appearance along a "wash" which is in the bottom of the cañon, and these are presumably where bedrock comes near the surface. Near one of these a knob of granite may be seen. At the northern end of this first ridge there are a few small and irregular areas of shale and limestone. These occur in a mass which appears to be one of the earliest intrusives. It is a porphyrite which will be described later. Rhyolite presents itself throughout the remainder of the ridge, with the hornblende andesite protruding through it in a few places, and also one small knob of granite near the southern end. The granite, shale, limestone and porphyrite is a basement complex corresponding to the Bedrock Series of the Sierra Nevada. The rhyolite, andesite and tuff may be regarded as members of a series that in a similar manner correspond to the Superjacent Series of that region. The remaining territory promises for the two major divisions, the members already mentioned and others additional. A couple of small exposures of iron-ore are at the base of the ridge; one near the southern end and the other with one of the limestone areas near the northern end.

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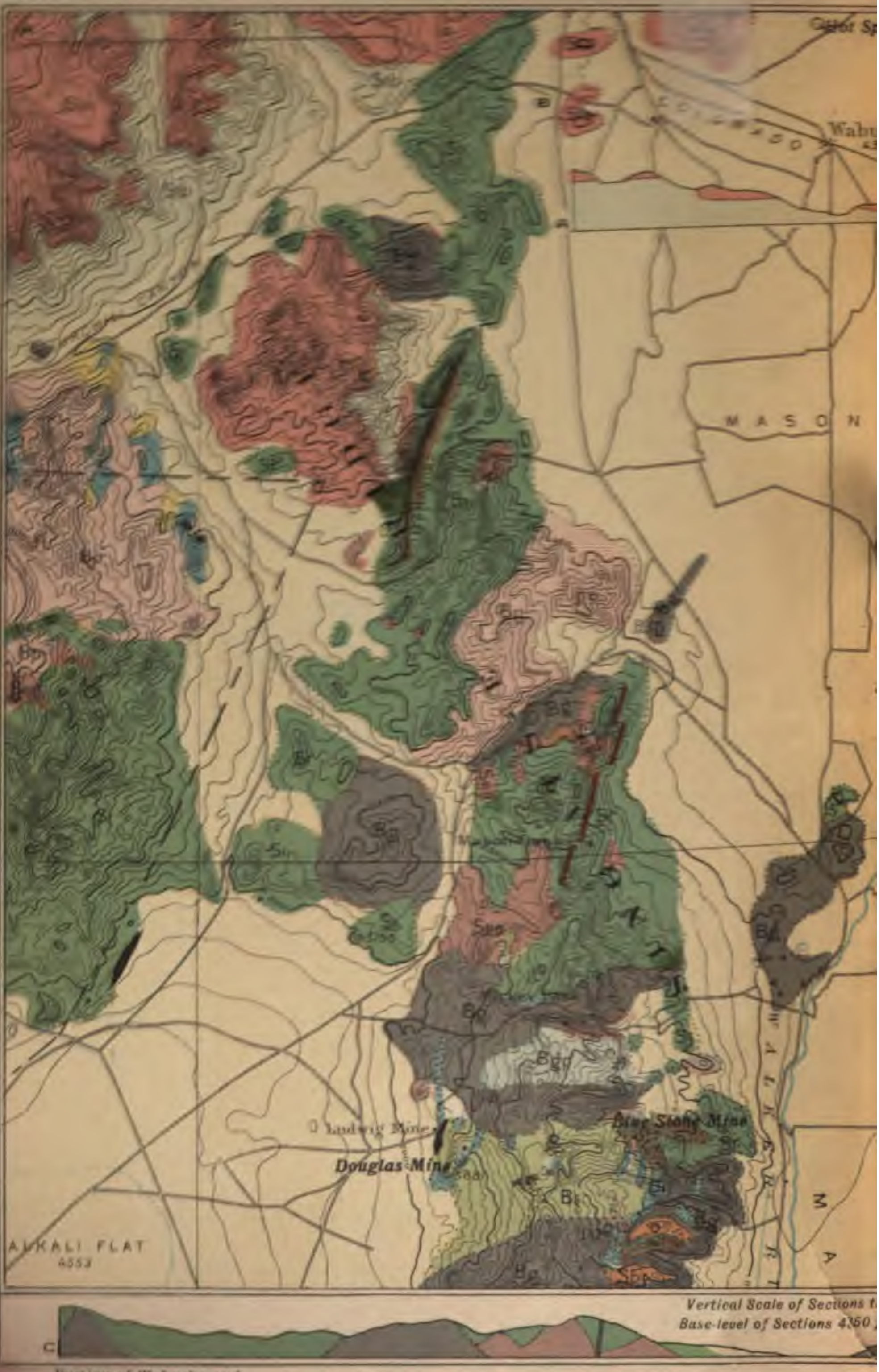
GEOLOGICAL MAP
UPPER REGION OF THE M



Portion of Wabuska and
Wellington Quadrangles
From Topography of U. S. G. S.

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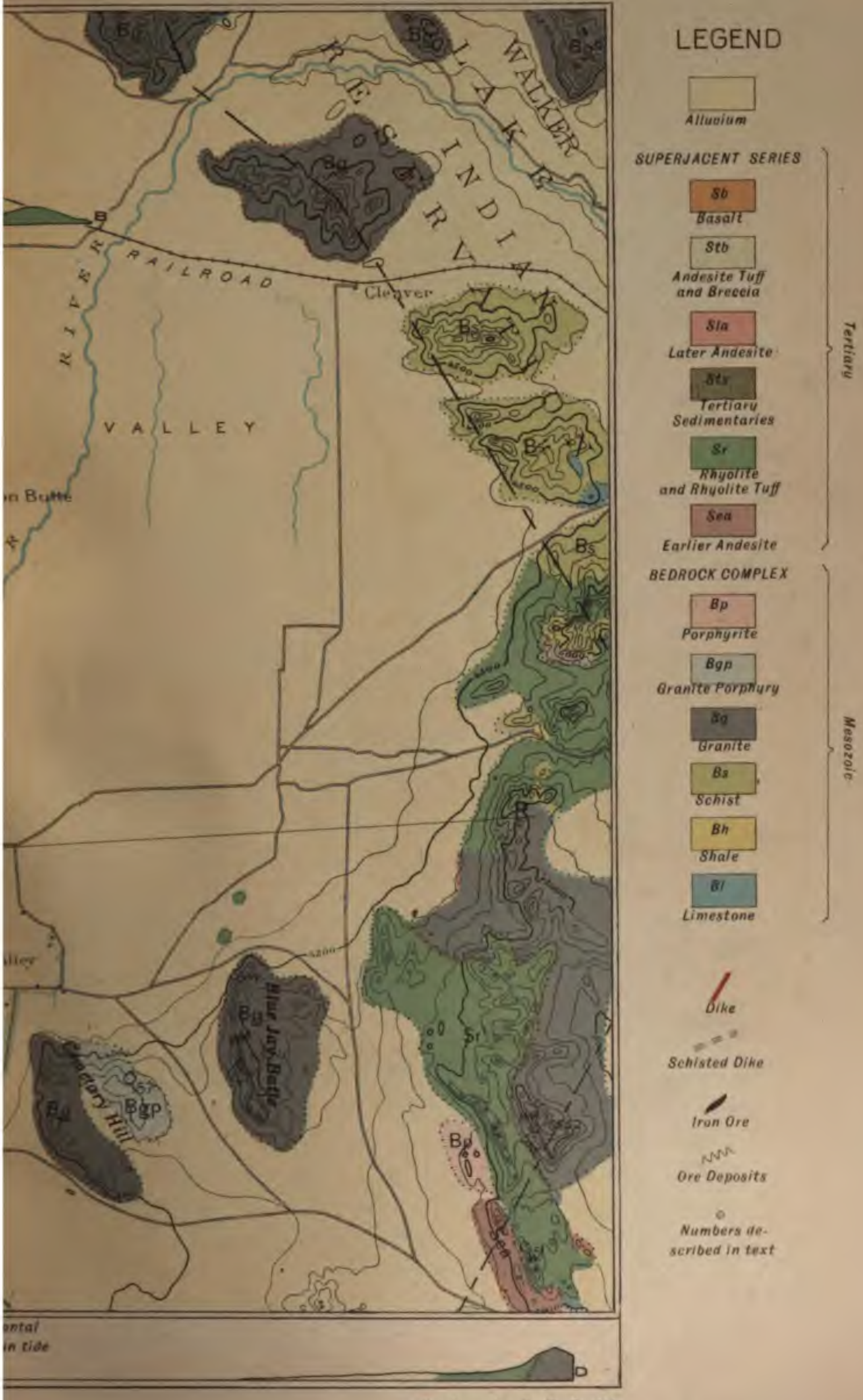

Geology by D. T. Smith

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ASTOR, LENOX AND
TILDEN FOUNDATIONS

Sing-ats'-e Ridge.—This ridge at the northern end, within the limits of the map Pl. 1, is made up of andesite and andesite tuff and breccia, similarly to the first ridge. The cap of later andesite, however, in this case is broken up, and along with it there is considerable of the breccia which is in the tuff; the breccia, in fact, forms nearly half of the cap. This is undoubtedly due to the tuff being easily eroded and carried away from around the blocks, thus leaving them residual. The only contact between the rhyolite and the tuff was found here, and its character is such that the relation of the rhyolite to the tuff

Note.—Suscribers to the Bulletin are requested to substitute the accompanying four pages in Vol. 4, No. 1, for the corresponding pages in the copies that have been sent, in order to correct error on page 6, due to transposition of lines.

Some good cleavage flakes of the feldspar gave extinction angles of andesite and labradorite, some flakes showing an optic axis nearly normal. This indicates the tuff to be andesitic. The material of the tuff is fine and splintery. The absence of all other rocks just mentioned from the tuff will be considered in another connection when the structure is discussed. The rhyolite makes its appearance along this second ridge in considerable force, and two dykes of rhyolite about four miles apart are quite marked; and along with one there occurs a dyke of the hornblende andesite. The two seem to mark the same line of fracture. West of this dyke there is an area of andesite and tuff, the latter showing some well stratified sandstone and some loose blocks of conglomerate; and midway of the ridge along the lowest cañon cutting across it an earlier intrusive is uncovered, as well as some granite and hornblende andesite. The rhyolite evidently formerly covered these areas. Near the south end of the second dyke the hornblende andesite and the rhyolite reach their highest altitude, and from this on the ridge, which is now still higher, is continued by granite and metamorphics, the rhyolite being relegated to the flanks of the ridge. The andesite is rarely to be seen from this on southward, and only then as a few loose blocks here and there, separated by dividing summits from that which is in place. Part of the stock from which it may have been derived may be covered by æolian sands or debris; or else these erratics are the remnants of a once extensive flow. The rhyolite near the southern dyke is frequently faulted, both transversely and lengthwise of the ridge, so that it is much broken. The contact which we now come to is that between the rhyolite and the granite. It appears to be not a fault contact from the evidence the writer was able to obtain. There was no contact metamorphism noticed, nor was there found any inclusion of the granite in the rhyolite. A small area of conglomerate is revealed near the contact where erosion has carved away the rhyolite. No bedding is shown, and every pebble, almost without exception, is faulted. The formation is not shown on the map Pl. 1, the area being too small. The rhyolite of this ridge appears not to present the structure which, according to the terminology of some writers, would be designated as sheeted. The andesite near by possesses this structure in a marked degree. At this contact the rhyolite ceases to be prominent in the ridge, and the hornblende andesite does not continue farther southward. The rocks that are now encountered are granite and granite-porphyry, schists, garnetiferous rocks, basalt and limestone. The contact between the granite and granite-porphyry is more irregular than it was possible to show on the map. The contact between the granite and the schists and garnet rocks is also irregular. The strike of the granite-porphyry is east and west, and it occurs as a very wide intrusive in the granite. The strike of the belt of schists is somewhat north of east. The belt of schists contains numerous segregations of copper ore, and a reef of exceptional interest, containing disseminated sulphides of copper and iron. It appears to be a metamophosed dyke. In places it has included in it a light colored rock, which may be pieces of the granite that were caught up at the time the dyke was filled. More will be said of this supposed dyke under the head of ore

Sing-ats'-e Ridge.—This ridge at the northern end, within the limits of the map Pl. 1, is made up of andesite and andesite tuff and breccia, similarly to the first ridge. The cap of later andesite, however, in this case is broken up, and along with it there is considerable of the breccia which is in the tuff; the breccia, in fact, forms nearly half of the cap. This is undoubtedly due to the tuff being easily eroded and carried away from around the blocks, thus leaving them residual. The only contact between the rhyolite and the tuff was found here, and its character is such that the relation of the rhyolite to the tuff could not be made out satisfactorily. The tuff is fragile, and a sharp contact was not to be expected. It shows no planes of slipping, and no pieces of the rhyolite were found in the tuff to indicate that there had been any faulting. The rhyolite appears from beneath the tuff, and in this connection the composition of the tuff is of some importance. The apparent absence of all other rock fragments from the tuff except the hornblende andesite is worthy of note, and perhaps of equal importance is the composition of the tuff aside from the hornblende andesite breccia it contains. There was found in it no quartz, but feldspar and a little dark colored ferro-magnesian mineral were observed. Some good cleavage flakes of the feldspar gave extinction angles of andesine and labradorite, some flakes showing an optic axis nearly normal. This indicates the tuff to be andesitic. The material of the tuff is fine and splintery. The absence of all other rocks just mentioned from the tuff will be considered in another connection when the structure is discussed. The rhyolite makes its appearance along this second ridge in considerable force, and two dykes of rhyolite about four miles apart are quite marked; and along with one there occurs a dyke of the hornblende andesite. The two seem to mark the same line of fracture. West of this dyke there is an area of andesite and tuff, the latter showing some well stratified sandstone and some loose blocks of conglomerates, and midway of the ridge along the lowest cañon cutting across it an earlier intrusive is uncovered, as well as some granite and hornblende andesite. The rhyolite evidently formerly covered these areas. Near the south end of the second dyke the hornblende andesite and the rhyolite reach unaltered and metamorphosed intrusives of the Bedrock Complex and rhyolite and hornblende andesite of the Superjacent Series are represented. The bedrock is limestone and granite, the latter being present in the lower half of the ridge and constituting the dominant rock.

A few gold and copper bearing veins occur in the southeast corner of the area of the map Pl. 1.

Tertiary beds which yielded fossils are exposed at the eastern base. Their exposure is not within the map, but about two miles east of it, and about two-thirds of the distance from the top. Their base is fine white rather sharp sandstone, and their top is conglomerate, with well rounded pebbles. The intermediate sandstone contains some hornblende and the pebbles are abundantly rhyolitic. There is also a yellowish and whitish stratum of chalky appearance. No test was made upon it to ascertain its composition, either chemically or mineralogically. The thickness of these beds was estimated to be twelve hundred feet.

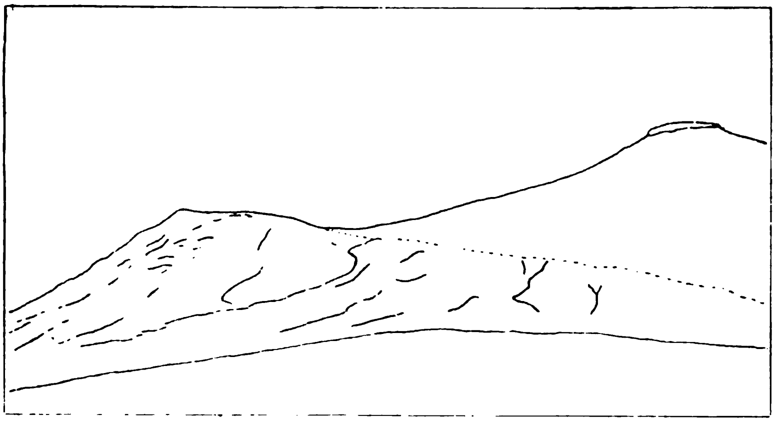
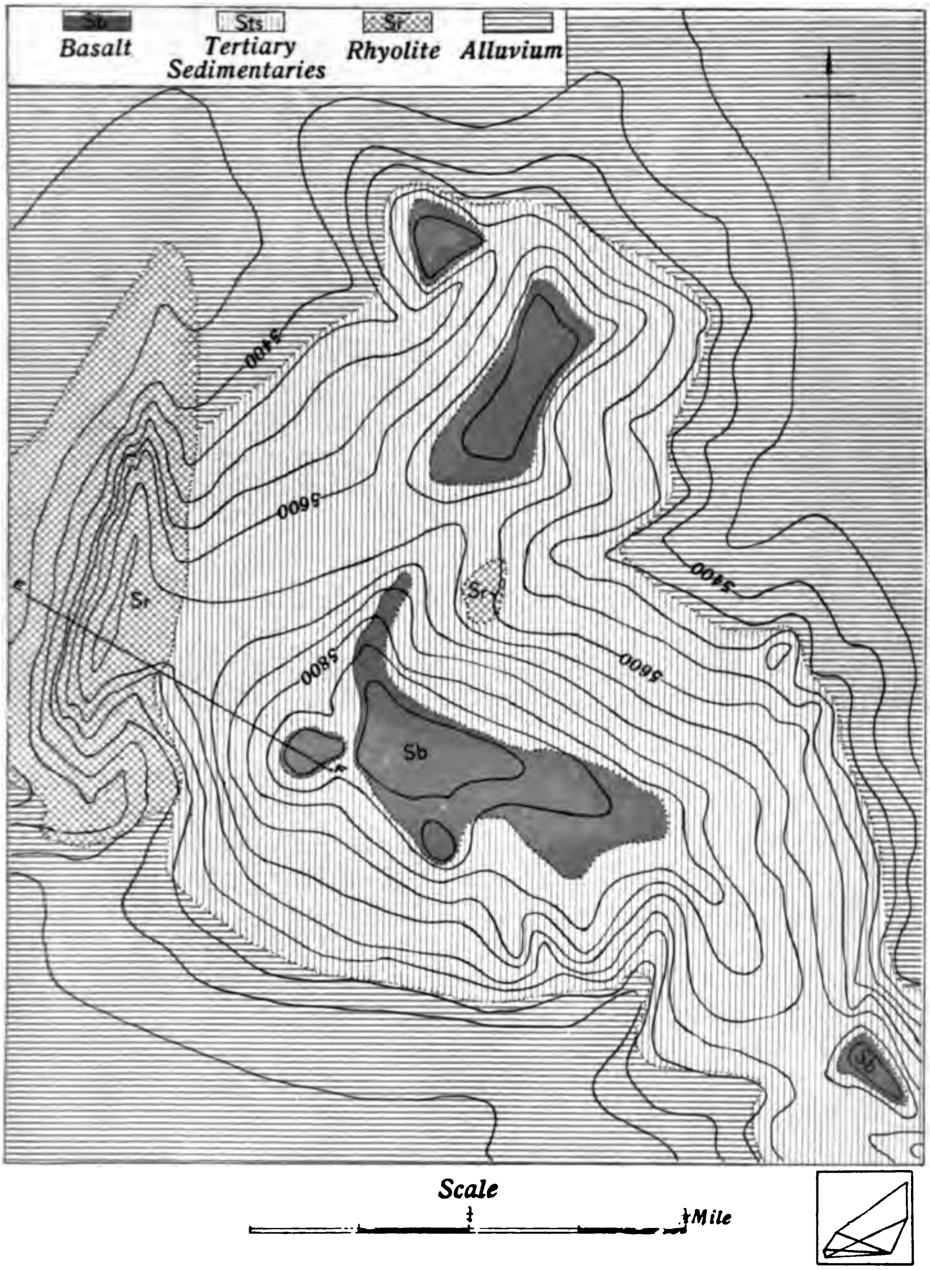


FIGURE 1.—Profile of a portion of Whirlwind Mountain along the line E-F in Pl. 2. The prominence on the right is a basaltic cap on sandstone. Along the broken line this sandstone rests on rhyolite, which rises to a pyramid on the left.

Whirlwind Mountain.—This ridge is shown on Pl. 2. It is made up of rhyolite, sandstone and a basalt cap, all being of the Superjacent Series. The relations of the basalt, sandstone and



Contour interval 50 feet

WHIRLWIND MOUNTAIN.

rhyolite are here well revealed, as may be seen by consulting Fig. 1. The basalt rests on the sandstone that overlies the rhyolite.

The Mid-valley Buttes.—The broad valley below the second or Sing-ats'-e Ridge is studded with four buttes which peer up through the alluvium. The northern one, Mason Butte, is composed of granite and dykes of hornblende andesite. There are no less than seven or eight of these that cut through the butte lengthwise. Another butte southeast of this one is made up of granite and rhyolite, and across the river are two more buttes, of which the more westerly is granite and granite-porphyry similar to that already mentioned in Sing-ats'-e Ridge, and the fourth butte is granite and earlier intrusives similar to that mentioned in the first ridge.

UNCONFORMITIES.

The sedimentaries occupy about one-thirtieth of the entire area. There is enough of them and a few fossils, however, to give information as to their age and the structure of the region. The range of the sedimentaries is from the end of the Palaeozoic or early Mesozoic to the present, as the fossils show. The Cretaceous and the Eocene are not recorded by any accumulations, but there are indications of considerable erosion which took place within a time that may correspond to these two periods. There was no section found where the entire column could be measured.

The Bedrock Complex and the Tertiary.—The unconformity between the shale and limestone of the Bedrock Complex and the beds of the Tertiary is usually very marked. The amount of disturbance and deformation of the complex is considerable, while that of the Tertiary is not so great. A few fossils indicate the limestone to be Triassic. In the Tertiary one pebble was found containing a fossil, which was submitted to Dr. J. P. Smith of Stanford University for determination of stratigraphical position, and the following communication was received: "The black silicious rock contains what appears to be *Daonella*, a pelecypod characteristic of the Middle Trias. The Geological Survey of California discovered some Triassic fossils[1] at Volcano, an abandoned mining district, thirty miles southeast of Walker Lake. Triassic fossils like those of the West Humboldt Range (Nevada) were also found near Wabuska. I think I have seen them in the Mining Bureau or in the Harvard collection. As I remember them, *Daonella dubia* (Gabb) was the most characteristic fossil—Lias.'"[1] The curator of the museum at the Mining bureau said that fossils from near Wabuska had been received and they were now stored and not available, but he was sure there were not many.

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[1] Described in Amer. Jour. of Conchology, Vol. V, by W. M. Gabb, "Description of some Mesozoic Fossils," etc.

A section south of west in the Pine Nut Range might yield further information of this character. So far as the writer is aware, these represent all the rocks of marine origin within the region.

The evidence for the Tertiary is perhaps a little more complete. The Tertiary is supposed to be of lacustrine or continental origin. The evidence for the lacustrine origin of the beds is perhaps not so complete as for their age. One portion of the evidence is the remains of a land fauna which they have yielded; and in this connection the following communication has been received from Dr. W. J. Sinclair, to whom they were submitted for determination: "The specimens submitted comprise fragments of the astragulus, calcaneum, and metapodals of a rhinoceros and the astragulus of a large camel. The presence of a large camel indicates that the beds from which the specimens were obtained are younger than the John Day. The John Day camels, belonging to the genus *Protomeryx,* are all small forms. The beds are probably late Miocene or Pliocene, corresponding to the Mascall and Rattlesnake formations of Oregon, but the material is not complete enough to determine these points with certainty." Of a date nearly twenty years earlier is the following[2] by Professor Russell: "Mammalian bones were obtained at a number of localities in the sides of the Humboldt and Walker River cañons, and, with the exception of a single vertebrate found in the medial gravels, they were all derived from the upper lacustral beds. These fossils were submitted to

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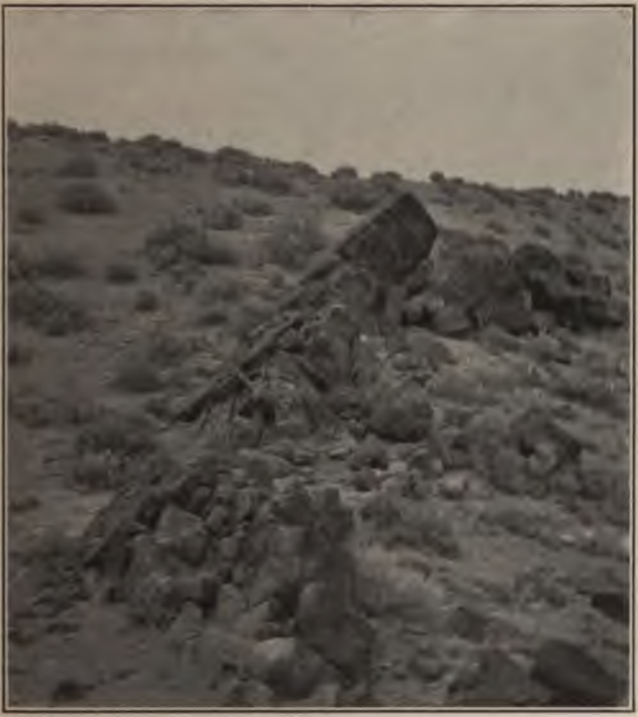
[1] Dr. Smith also kindly adds that he has reviewed the fossils from Volcano in the Harvard collection, and found their determination correct.

[2] Mon. XI, U.S.G.S., p. 238.



Showing the westward dip of the Tertiary Strata.

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Professor O. C. Marsh for determination, but only a partial report of their character has been rendered. So far as determined, they include a proboscidian (elephant or mastodon), a horse, an ox, and a camel. The fossils were usually detached and scattered through the sediments, more than one or two bones of the same individual being seldom found at a single locality." This refers to the Quaternary, and the medial gravels referred to are those of the Lahontan beds. The detached occurrence of the fossils is the same as in the case of the Tertiary. The fossils which the writer found were dug from strata tilted about 35°, an amount which is greater than was at any place recognized in the Quaternary. Pl. 3 shows the amount of tilting. Whether the species are the same in the two instances it is impossible to say, but apparently they are not; and there can be no doubt as to the relative position of the two sets of beds. Professor Russell has mentioned the possibility of fossils being derived from lower beds. However, the amount of their deformation apparently is on the side of their being Tertiary. The beds show clearly a gradation of material from fine to coarse.[1] The finer sandstone shows some sharp grains which may be of volcanic origin. The apparent absence of fossils of an aqueous life might be regarded as an indication of volcanic origin for the whole of such strata, but this for the greater part is not true.

Specific correlation of the Tertiary beds throughout the Great Basin continues to be on the whole not very satisfactory. Erosion and alluvium isolate and cover them to such a degree that it is impossible to trace them continuously. The value to be placed on their fossil life seems to be somewhat uncertain, with the conclusion of work in each separate region so far investigated.

The Tertiary and Quaternary.—The unconformity between these is quite sharp. The latter lies very level, and it is mostly obliterated within the area shown on the maps, but in the northeast and northwest corners of Mason Valley lacustrine beds and terraces are preserved. Their thickness, measured in the Walker River Cañon is one hundred and sixty feet.[2]

West of the second, or Sing-ats'-e Ridge, and south of the map Pl. 1, in Smith Valley, are a few hundred feet of beds which are revealed as a result of the cañon cutting by the West Walker. These beds appear to be horizontal, and it is difficult to say whether they are Quaternary or Upper Tertiary. A few large bones have been found on their surface, and, as a matter of record, it may be here stated that a few large bones have been reported as found in building a road grade in the Wassuck Range, southeast of these beds, and also that fish impressions occur at the mouth of the cañon just mentioned as cut by the West Walker.

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[1] Bull. Dept. Geol., Univ. Calif., Vol. 2, No. 9.

[2] Mon. XI, U. S. G. S., p. 141.

Relative Age and Unconformity of the Igneous Rocks.—The unconformity between the Bedrock Complex and the Superjacent Series is also well brought out by the stratigraphic relations of the igneous rocks of the two groups. The granites and granite-porphyries of the Bedrock Complex appear to be intruded into the Triassic, and cutting these are dykes of porphyrite, which is perhaps also of the complex. The hornblende andesite reposes in tilted attitudes upon the tilted abraded surface of the Bedrock Complex. This was followed by the rhyolite, which is found intrusive in the andesite in the form of tongues. Both the hornblende andesite and the rhyolite yielded pebbles to the shore drift of the Tertiary lakes which succeeded the extravasation of the rhyolite. But the andesite is not so abundantly represented as the rhyolite. The next lavas in order of occurrence are the later andesite and the basalt. These two lavas apparently succeeded the lacustral epoch, since they yielded no pebbles to the Tertiary Lake beds. The later andesite and the basalt approximate horizontality. They both occupy eminences and may be regarded as caps. The basalt occurs in many isolated and detached areas, and these all, with the exception of that on the Wassuck Range, are of the same altitude as the later andesite cap.

STRUCTURE.

The Bedrock Complex.—The Triassic limestones are much crumpled, folded and broken, and the accompanying batholithic intrusions of granite and porphyries are also much fractured and broken. The bedding planes of the shale are not exposed. The axis of folding is nearly north and south, and there are indications, at least, that this structure would not be apparent in the present topography were it not that the direction of subsequent faulting coincided with it very closely; thus, following the establishment of the Bedrock Complex, there apparently intervened a considerable period of erosion which wore it down to a low relief.

The Tertiary.—The dip of the Tertiary beds is about forty degrees to the west, and they present a series of monoclines, and the apparently plain-like surface on which the rhyolite rests is also similarly inclined. The dip of it and that of the beds is nearly the same. There are some bands of stratification in the tuff lying under the later andesite cap, but their tilting is somewhat less. The altitudes are in striking contrast to the verticality of the schists of the underlying Bedrock Complex. These schists, moreover, strike northwest and southeast. The region is divided by parallel ridges, which may be classed in two systems—those trending northerly and somewhat westerly, and those approximately at right angles to these. The westward alluvium slopes are many times longer than the eastward slopes, and the crest of each system of ridges pitches toward the base of the other: for example, the pitch of the third ridge shown along the east margin of Pl. 1 pitches north to the base of Cleaver Mountain, which is just north, off the map, and it trends nearly east and west. By pitch is meant the slope of crest-line. The pitch of that mountain is also westward toward the base of Sing-ats'-e Ridge. The crest of this last ridge pitches northward toward the base of Cleaver Mountain, but the pitch is not as great as in the case of the other north-south ridge, which, as may be seen on the map, is broken into several buttes at its northern end. The degrees of these respective pitches seems to be nearly proportional, for the highest point, Cleaver Peak, is in line with the chain of buttes. Some notion of these relations may be obtained by consulting the Wabuska sheet and Fig. 1; and, as to the general block tilting of the Cleaver Range both parallel to its trend and transversely, an idea may be had by consulting the earlier topographical map[1] of that range. This range is capped with basalt, and it has been seen from two sides, so there may not be great doubt as to the accuracy of the observation. This mountain presents a bold face toward the south, overlooking the alluvium plane below; and at the base, not near either of the north-south ranges, there are hot springs. At the eastern base of Sing-ats'-e Ridge and about nine miles south of the map Pl. 1, steam issues from the rocks. In Smith Valley at Wellington, near the eastern base of the Pine Nut Range, is a well the water of which is too warm for drinking purposes; and at the same base, and about twelve miles north of this last place, at Hind's Hot Springs, there is one at scalding heat. Thus, at the base of each of the systems there are hot springs. Wherever the transverse system is not present the valleys are closed by an arrangement of ridges *en echlon.*

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[1] Map No. 48, Wheeler Survey West of 100th Meridian.

There are several features that are conformable to the two systems within the area mapped and near to it; as for instance, to the transverse system there are the course of the cañons, strike of the andesite and rhyolite dykes, strike of the schists, trend of two of the mid-valley buttes and outcrop of several of the mineral veins. The third butte and the remainder of the mineral veins are conformable to the other system, while the fourth butte is circular, or conformable to both.

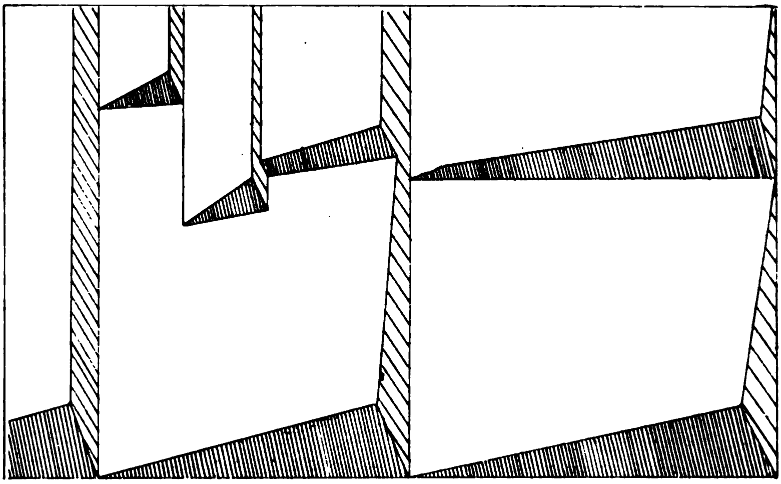
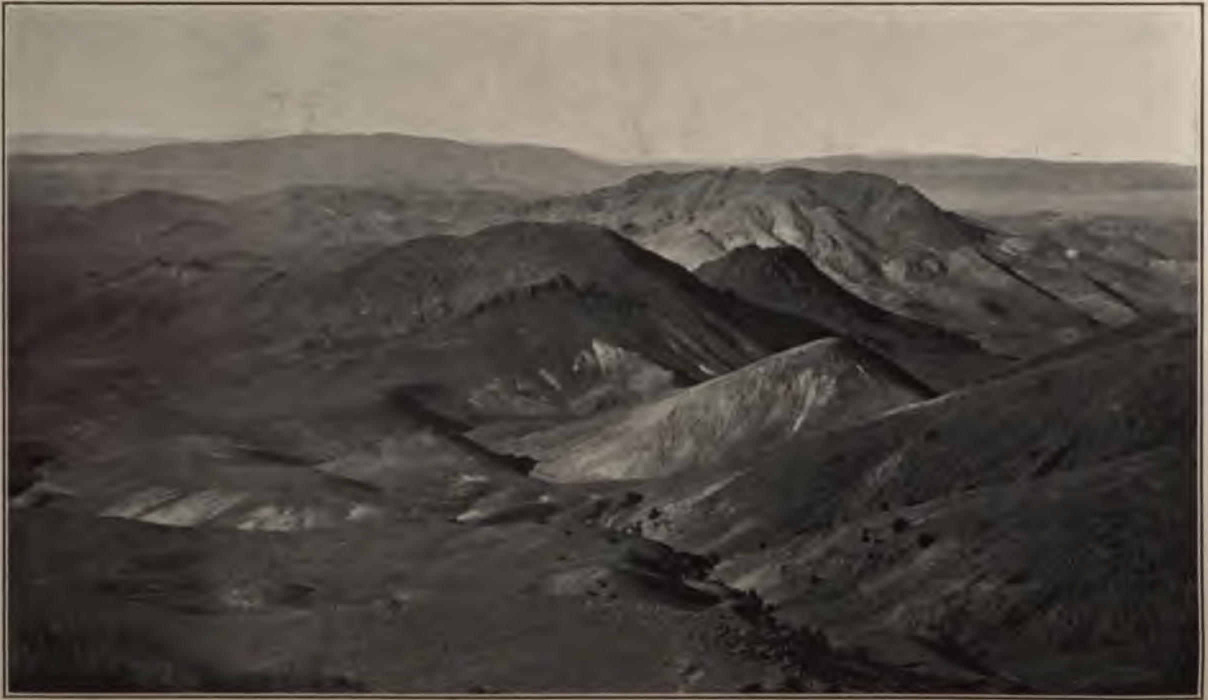


FIGURE 2.—Ideal representation of the structure of Walker River region.

Fig. 2 shows somewhat ideally the type of structure that is presented in the region; and it is believed that this region offers fair opportunities for a quantitative study of the generally rec-



Illustrating the geomorphy of the region where the rhyolite is a prominent feature. On the left is the northern end of Mason Valley and on the right the Walker River Valley. In the distance is the Cleaver Mountain Range. This range is capped with basalt the dip of which is indicated by the sky-line. The range is just north of the map, Plate 1.

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ognized Basin Range structure, since there appears to be a degree of proportionality between the north-south system of faulting and the east-west system.

RELIEF OF PRE-TERTIARY AND TERTIARY SURFACES AS COMPARED WITH PRESENT RELIEF.

That considerable time has elapsed since the faulting began, and that it was apparently periodic in its progress, seems to be evident. The absence of granite pebbles from the Tertiary and the presence in it of the rhyolite, which the writer has shown was subsequent to the earlier andesite, would indicate that the surface of the region was reduced to one of low relief previous to the efflux of the rhyolite and the appearance of the Tertiary lake, the granite being reduced to a position below the erosion zone. This is also rendered apparent by three other considerations: the surface on which the rhyolite rests presents a plain-like character; the several isolated and detached areas of the rhyolite have the dip of this plain-like surface, and this is nearly uniformly the same for each; and this dip is also practically the same as that of the beds of the Tertiary. It may be possible, from the relative proportion of the earlier andesite in the Tertiary, to fix the date of the completion of this planation more definitely: that is, to place it after the effusion of the earlier andesite. It is possible that the lower portion of the Tertiary accumulations are in part granitic debris, but the upper portions certainly are not. This would extend the period of planation into the early Tertiary.

The consideration of the basaltic sheet is somewhat of a similar character. The isolation of the areas, their sheet-like character, and their similarity of elevation seems to indicate that they once were all connected. The later andesite can be regarded as an associate on the same elevation. If these areas were once connected, it would seem to indicate that the surface had been reduced to that of a peneplain, and that the ridges have been subsequently lifted. The distance between these areas is hardly less than ten miles in any instance; and supposing them to be on the upturned edge of a block the width of which is that much, the amount of rotation or tilting would be less than a degree and a quarter to lift the edge above the floor of the valley a thousand feet. This is a surprisingly small amount of rotation, and the attitude of the lava might easily be mistaken for horizontal. However, it has been considered that the separated basalt sheets of the Great Basin were never connected.[1] A few basic dykes were found within and near the areas of Pls. 1 and 2, and it may be possible to trace the basalt to them. The character of the material is such that a very narrow fissure might discharge considerable molten rock, since the basicity of the rock indicates a great degree of fluidity at a comparatively low temperature. While the latter hypothesis attempts to account for their isolation, it remains to be seen how to account for their attitude. This is one of the questions that arose that was not answered beyond the attempt indicated. The author's opportunity did not permit of his making any further investigation.

EXPLORATIONS BEYOND THE REGION MAPPED.

It was the writer's opportunity to make an excursion to the West Walker and through Carson Valley. This gave him an occasion to make some observations of a general character. The structure of the first system was found to prevail, with now and then suggestions of the transverse system. The West Walker flows through two valleys before it reaches the Main Walker. In flowing through the first of these (Antelope Valley) it bears along near the eastern base of the mountains at the west for a considerable distance, and at the northern end of the valley the course is northeast, passing through the Pine Nut Range, which is very low at that point, there being a considerable mass immediately north. The river then turn sharply to the north and swings eastward across the valley, being entrenched on a flood-plain between two bluffs of sandstone. These bluffs are the beds of sandstone that were referred to as of uncertain age when the unconformity of the Tertiary and Quaternary was considered. The bluffs converge toward the east, and the river is more and more confined between them. The stream runs near the base of the northern bluff, and is gradually invading it, thus gradually taking a more and more northward direction, which seems to indicate a tendency of the river to change its course and flow along the western margin of the valley near the steep eastern face of the Pine Nut Range; but so long as the river is constrained to remain in the present cañon of the Sing-ats'-e Ridge, the tendency is somewhat offset, and the gradual invasion of the northern bluff is probably only a manifestation of such tendency. The river after emerging toward the open valley continues in the direction of the cañon for a short distance, but it soon turns quickly to the north, bearing a little to the west; this being the general direction of the base of the ridge. It is joined by the East Walker at a point about two miles south of the map Pl. 1. The East Walker flows in a cañon-valley throughout almost its entire length and, therefore, this valley does not show the difference of the valley slopes that is shown in the wider valleys. Walker Lake lies under the steep eastern slope of the Wassuck Range, and from the eastern and southern shores the ground rises gently. So much for the Walker River System. As to the Carson River, which has its source near the West Walker, it flows near the eastern base of the mountains just east of Lake Tahoe, and Carson Valley has a more or less gentle eastward rise to the summit of the Pine Nut Range.

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[1] Mr. G. K. Gilbert, Surveys West of the Hundredth Meridian, Vol. III, p. 125.

DESCRIPTION OF THE IGNEOUS ROCKS.

The numbers on the maps indicate approximately the places where the samples were taken. The hand-specimens and the corresponding thin sections bear the same number as the place. The region was not traversed consecutively, hence the reason for the numbering being apparently at random.

The Granitic Rocks.—Hand-specimen No. 123 is a fair representative of the granitic rocks that occur in the southeastern portions of the map Pl. 1. This rock has an even grained granitic structure (allotriomorphic granular), and is made up of feldspar, quartz, biotite and a greenish ferro-magnesian mineral. The color is grayish and the fracture is irregular. Microscopically the structure is granitic; no mineral has idiomorphic outline. The essential minerals are biotite, augite, plagioclase, orthoclase, and quartz. Magnetite in somewhat irregular grains, 0.25 mm. in size, is distributed throughout all the essential minerals. This mineral is apparently original when possessing that size in this rock. The biotite is brown and in irregular crystals, often with dimensions normal and parallel to *c* about equal. It shows a leaching to a green variety, and a further change to chlorite and black specks of iron oxide.

The ferro-magnesian mineral agrees very well with augite. It is nearly colorless and practically free from pleochroism. A section nearly normal to the prism, ∞ P (110), shows a cleavage angle of about 90°, and the extinction bisects this angle. There is an alteration of the mineral to a green pleochroic one, possessing an absorption color of yellow-green which has some of the properties of epidote; the alteration, however, is incipient. Green hornblende is also present. It seems in some instances to have been derived from augite. The plagioclase feldspar shows no alteration to calcite, but contains kaolin. No properly orientated sections were found in which to measure extinction angles of the lamellar twinning. Orthoclase distinguishable by lowest relief and birefringence and freedom from lamellar twinning is present. Quartz with irregular cracks, and possessing gas and liquid inclusions, is of similar importance. Some apatite, 0.8 mm long, is present. This rock may accordingly be designated an augite granite. Another similar rock is 172, which occurs east of it in the Blue Jay Butte. The similarity of the two is marked. The biotite is less altered and the rock on the whole is fresher. In the pyroxene, in sections showing a very pronounced prismatic cleavage, there appears a fine lamellar cleavage which is somewhat discontinuous yet pronounced, and cutting across the coarser at a considerable angle. This lamellar cleavage is basal, and indicates the species diopside. An extinction with the coarse cleavage was obtained in one case as large as 32° on a section parallel to *c*. The prismatic cleavage is straight and well defined. The alteration of the pyroxene is the same as in slide 123. It shows apparent incipient change to a green pleochroic hornblende. In one instance where the pyroxene is surrounded by a considerable border of hornblende, iron oxide is traced along their contact, the hornblende itself being free from it. Biotite includes quartz and pyroxene. In regard to the latter, it occurs both as inclusions and intergrowths, and their relation is such in either case as to indicate that the period of crystallization of the biotite continued beyond that of the pyroxene. The feldspar is the same as is usually seen in granitic rocks. The extinction of orthoclase was obtained in the section of the clinopinacoid, $\infty \mathrm{P} \acute{\infty}$, (010). It was further recognized by a relief lower than quartz. The plagioclase is larger, having dimensions of 0.5 mm. and 1.5 mm. It contains inclusions of biotite, pyroxene partly altered to green hornblende, iron ore, some of which shows crystal faces, and hexagonal and lath-shaped sections of apatite. Some of the larger plagioclases include smaller ones of a slightly different orientation. Magnetite occurs in all the essential minerals, and is mostly devoid of crystal faces.

The occurrence of pyroxene in these two rocks indicates that they belong to, perhaps, a less frequent class of rocks, namely, the augite granites. It should be noted that these rocks show effects of pressure, since many of the minerals show wavy extinction and small crystals are faulted.

The next three rocks, Nos. 94, 95 and 157, show remarkable similarity. They are all samples of the granite-porphyry dyke. Nos. 94 and 95 were obtained west of the river, in Sing-ats'-e Ridge, below the middle of the ridge, and No. 157 was obtained in Cemetery Hill. The rock possesses porphyritic structure. Carlsbad phenocrysts 1 cm. in length, in granular groundmass of about 2 mm., is characteristic. The groundmass is phaneric, and its mineral content is readily recognizable in the hand-specimen. There is some difference in the ferro-magnesian content. There is less of it in 157 than in 94, but No. 161, which will not be described, is from the same exposure as No. 94, and it shows less biotite. The hornblende seems to be as abundant in one case as the other. In 95 the light and dark colored minerals are about equally abundant. In the microscopic slides of all three the phenocrysts are microcline, which is recognized by the combination of albite and pericline twins, which are very fine and have an equal and simultaneous extinction. The groundmass is made up of microcline, plagioclase, quartz, biotite and hornblende. The grain of the groundmass varies from 1.5 mm. to 2 mm. The biotite is brown, with some leaching to a green color. The hornblende is original, as it shows in sections normal to *c* the prism and clino-pinacoidal faces $\infty \mathrm{P}\,(110)$, and $\infty \mathrm{P} \acute{\infty}$ (010), and the prism faces are at an angle to one another of 125°. This also is the angle of the cleavages. The color is green.

There is no chlorite or calcite, but in slide 95 there is some epidote. The epidote has irregular outline, but its absorption tint (pistachio green), high relief and strong double refraction in nearly equally dimensional sections make its identification quite certain. It has apparently replaced hornblende. A considerable portion of the feldspar is somewhat elongated in the zone $\infty P \infty : OP(100:001)$. No section normal to $\infty P \breve{\infty}$ (010), was found in which to measure extinction angles of the albite twins. Carlsbad twins are numerous. In sections nearly parallel to the brachypinacoid the axial figure is only a little to one side, and the axial plane makes an angle of a few degrees with the most pronounced cleavage, which is the basal. Hence it is quite certain these feldspars are not very basic. Quartz often contains plagioclase, as also does microcline. Apatite and sphene are present, and the latter is frequently of irregular outline and of good size. There is magnetite present, and in slide 95 a black opaque mineral with narrow border of sphene may occasionally be seen, especially in the larger crystals of hornblende. It may be ilmenite. In slide 94 the association of sphene, hornblende, biotite and magnetite is marked. Strain effects are apparent, as many minerals have a wavy extinction and show slight faulting. Apatite needles are broken and slightly displaced. No indication could be obtained that any movement had taken place during the crystallization of the rock. The following analysis was made of specimen 94:

	Per Cent.
SiO_2	67.70
*Al_2O_3	15.95
*Fe_2O_3	1.53
*FeO	1.14
*MgO	1.23
*CaO	2.70
*K_2O	3.74
*Na_2O	4.83
H_2O @ 105° C	0.19
H_2O.@ ignition	0.36
TiO_2	0.23
MnO, present, not determined.	
P_2O_5, present, not determined.	
Total	99.60

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*These were duplicated, and were concordant within .06 per cent.

Specimen 100 occurs at the south margin of the map Pl. 1, in Sing-ats'-e Ridge. It is an even-grained rock, made up of about equal amounts of light and dark colored minerals. The light colored minerals are feldspar and quartz. Biotite and hornblende are easily recognizable. The slide contains plagioclase feldspar, whose extinction angle in the zone normal to the brachypinacoid $\infty P \breve{\infty}$ (010) is symmetrically 14°, but the sign was not determinable, and this one measured was not a Carlsbad twin, hence the tables of Michel Lévy could not be used. Some of the plagioclase attains a length of 2 mm. Microcline and quartz of about equal grain are present, but the plagioclase predominates. Green hornblende of a length of 2 mm. is present and in size about equal to the plagioclase. There is less of the biotite than hornblende, and there is less iron oxide in this slide than in the previous slides. Sphene in part idiomorphic toward microcline and allotrimorphic toward plagioclase is a constituent. This rock may be termed a biotite granite. No. 120 is a similar rock. It occurs farther south, off the map Pl. 1, in the same ridge and under the basalt cap west of Nordyke. In the hand-specimen the feldspars are of two colors, brownish and white. These are about of the same dimensions and about equally abundant. The remainder of the rock, about one-third of it, is hornblende. The average size of the first named minerals is a little less than 0.5 cm., and that of the hornblende about 3 mm. The contrast of colors readily characterizes the rock in the field. In the slide the brownish colored feldspar is orthoclase. Its color is due to dust-like impurities. The plagioclase is clear for the most part. Biotite is absent and the hornblende is of a greenish color. No mineral is idiomorphic except some accessories. The iron ore has irregular shape and shows a preference for the hornblende. The slide as a whole shows considerable fracturing of the rock, and thus indicates the disturbance to which it has been submitted, as seen in the field. The disturbance evidently was not long continued, for no mineral indicating dynamic metamorphism is recognized, and this is equally true of all the slides thus far examined, unless epidote and microcline be so regarded. The necessary water for hydration of the iron and lime to produce epidote may be derived from the water found in the bubble inclusions of the quartz. In the case of those rocks containing biotite it may be due to decomposition of that mineral, but in the present instance it is not clear from what source the water was derived, for the bubble inclusions occur along the fractures of the quartz.

No. 89 is an even grained rock, composed of light green hornblende and feldspar, showing polysynthetic twinning as viewed in the hand-specimen. The rock occurs at the east base of Sing-ats'-e Ridge, and half way from the top of the map Pl. 1. It apparently is not of great extent. Hornblende appears to be about one-third of the rock. The grain of the rock is about 2.5 mm. In the slide the last named mineral is pale green and somewhat pleochroic. No section normal to the prisms was obtained in which to measure cleavage angles, but in some sections, showing the cleavages parallel or very nearly so, the extinction was as great as 15° or over. The cleavage is very fine and lamellar. Orthoclase and quartz have less prominence. The plagioclase differs not essentially from that seen in previous sections. They show zonal structure, and their decomposition has had zonal progress. The quartz is fractured, and through its rifts are minute liquid inclusions. The cracks are quite parallel throughout the slide.

No. 141 is the granite of Mason Butte. The light and dark minerals are about of equal proportions. The dark minerals are hornblende, biotite and chlorite. Epidote is noticeable. Quartz and feldspar comprise the light colored minerals. The average grain of the rock is 4 mm. In the slides the feldspar appears to be mostly orthoclase, since it is free from lamellar twinning and possesses low relief and birefringence. Quartz is next in importance, and there are a few individuals of microcline. The hornlende is sparingly present, its cleavage and form normal to prism zone indicating its presence beyond doubt. Brown biotite is believed to have been once present in an abundance, for chlorite, with a few remaining shreds of brown biotite, is very plentiful. The chlorite shows the micaceous cleavage, and the extinction is parallel to the cleavage. Its very low double refraction, "ultra blue," between crossed nicols, makes it easily recognizable. Some iron ore and perhaps secondary silica is in evidence. Epidote is easily recognizable by its relief and strong double refraction. It is thought to be secondary because of its intimate association with chlorite, and it is idiomorphic toward the chlorite and thus antedates it in formation. The necessary ingredients for these products doubtless were derived from the ferro-magnesian minerals for the most part. Much of the quartz possesses inclusions along cracks, and the latter preserve nearly a singleness of direction. The feldspar also shows alteration to a fine fibrous or shredded mineral giving interference colors of yellow and green of the second order. It is thought to be sericite. The epidote shows fracturing, so that it was formed previous to the general deformation suffered by the rock. This rock evidently would be termed a biotite granite.

No. 77 is a representative sample of the granite south of Mickey Pass. It is a nearly white rock, being sprinkled throughout with hornblende 4 mm. in average length, the quartz is present, fairly idiomorphic, and of a width of 3 mm. Feldspar forms most of the rock, and twinning is apparent, though the rock is somewhat altered. The rock is porphyritic. This rock is somewhat similar to Nos. 94, 95 and 157, and its only apparent difference is that it is more acidic. No. 109, which occurs near the Ludwig Mine, differs only a little from it, and that in containing a little epidote. The groundmass is very fine, and is resoluble with difficulty.

The Porphyrite.—This rock was not studied microscopically. It occurs in the north end of the first ridge shown on Pl. 1, and also in a few dykes in the third ridge and Blue Jay Butte. It is a porphyritic rock, apparently free from quartz, and has a dark colored aphanitic groundmass in which are phenocrysts of feldspar averaging from 3 mm. to 4 mm. in length.

The Hornblende Andesite.—No. 142 is from the dykes of Mason Butte, and 146 is from near Mickey Pass. Phenocrysts of dark hornblende are inclosed in a light blue or lavender colored groundmass. The hornblende is abundant and from 2 mm. to 3 mm. in length. Occasionally the feldspar assumes a length of 1.5 mm. The rock weathers to a dull red color, and may easily be confounded at a distance with the later andesite and with the rhyolite. The hornblende is occasionally twinned. The feldspar shows a growth by zones which have not been equally spaced, and sections approximating parallelism to $\infty P \breve{\infty}$ (010) have a variation of extinction of 16° from center to periphery. The extinction of labradorite was obtained for the peripheral zones. Squares of magnetite 0.12 mm. are frequent, and small and large sized crystals of apatite are abundant. Some flow structure is exhibited for the earlier products of crystallization. The groundmass remains equally luminous between crossed nicols when the stage is rotated; and with a high power and intense light there seems to be no glass present; and apparently it is wholly feldspathic. The larger phenocrysts of feldspar exhibit the phenomena of resorption and subsequent growth, and their outline is less regular than the smaller sized ones. Calcite, as an alteration product, pervades both the groundmass and the phenocrysts, and chlorite occurs only in 142. The hornblende of No. 146 shows a marginal lighter color and a breaking down into a fibrous or leafy aggregate which is notably free from chlorite. The hornblende is often fractured and dislocated. Apatite occurs in stout prisms, and in some instances without idiomorphic outline. Magnetite, which is in grains rather too large to be considered secondary in this rock, takes form against the apatite irregularly, with a tendency to inclose it. This indicates that the magnetite and apatite had crystallized contemporaneously, but that the magnetite had continued longer to crystallize. Some of the apatite shows embayments and inlets suggestive of corrosion, and in these are calcite. It is also somewhat fractured, and it is perhaps in the groundmass that the record comparable to that already found in the granite, of the general dynamic effects which are the result of the deformation of the region, are found. The flowage of the molten rock, which more or less fractured the phenocrysts, makes it evident that, in studying the dynamic effects as revealed in the rock, any disturbance that affected the groundmass after it crystallized should be distinguished from that which had affected the phenocrysts during their movement. In the case of the phenocrysts the effects due to movement in the magma are, in the present rock, greater than those due to deformation after the rock had crystallized; hence it is in the groundmass that the record is clear. The effect is apparent through the groundmass, but it does not show any indications of dynamic mineralization.

The Later Andesite.—This rock occurs as a cap in the northwest corner of the map Pl. 1. Specimen No. 131 is representative. The color of the rock is red, both on the weathered and fresh fractured surfaces. There are numerous phenocrysts of feldspar, 2 mm. to 4 mm. long, inclosed in a groundmass. The specific gravity of the feldspar was determined by a heavy solution to be 2.685, thus indicating it to be a basic andesine or acid labradorite. The evidence obtainable in the slide was not sufficient to be confirmatory. No quartz was detected, and a determination of the silica gave 57 per cent., which clearly indicates the rock to be an andesite. A few large phenocrysts of feldspar in the slide are polysynthetically twinned, and they show zonal growth. Occasionally the centers of the phenocrysts contain numerous inclusions, while the margins are free, and a few crystals of hornblende of lesser size are present. The groundmass contains innumerable lath-feldspars and an abundance of a translucent mineral of a reddish brown color and of rectangular cross-section. It may be a pseudomorphic replacement of hornblende by limonite. There is no parallelism of structure in the groundmass, and no glass.

The Rhyolite.—This rock is well represented over the region. It weathers to a reddish color, and on a fresh fracture it is somewhat lighter. It often contains foreign material, such as fragments of the surface over which it flowed. Quartz, glassy feldspar and some biotite are noticeable in the specimens. Lying usually under this rock is a white one which appears rather tufaceous, and on the weathered surface of this latter may be found dihexhedral quartz crystals 3 mm. to 4 mm. in length; also a glassy, idiomorphic feldspar of similar size. These crystals of feldspar and quartz are frequently corroded and often fractured. The pyramidal faces of the quartz are well represented, and there is usually a prism face in evidence. Faces corresponding to the following are recognized on the feldspar: OP (001), ∞P (110), $2P\bar{\infty}$ (201 and $20\bar{1}$), $P\infty$ (101), P (111), P3, (130) and (130), $\infty P\infty$ (010), and $2P\infty$ (021 and $0\bar{2}1$). In the sections only one of the phenocrysts could be measured for a positive result. A section normal to the brachypinacoid, $\infty P \breve{\infty}$ (010) of a crystal possessing lamellar twinning shows the two feldspar cleavages, one parallel to the twinning and the other more pronounced at approximately the feldspar angle. The extinction is nearly symmetrically 20° to the twinning lines, and the biaxial figure is nearly central. A section possessing such characters indicates it beyond doubt to be albite. Another crystal has characters which suggest in a rock like this one the soda-lime feldspar, oligoclase. Sections from different portions of the rhyolite vary somewhat as to ferro-magnesian content. Some specimens contain hornblende with biotite, while other specimens, from other localities, contain either alone. The biotite is often bent, and fluidal structure is exhibited. It and the hornblende show alteration to magnetite and hematite. Many of the feldspar phenocrysts show a marginal growth and a concluding corrosive action. The quartz and feldspar usually show embayments and inlets of the groundmass, and rounded corners. Subsequently there was a fracturing of the phenocrysts and migration of sharp, angular pieces. The groundmass is red and cloudy from inclusions. Spherulitic structure is shown to some extent. From the opacity of the groundmass it is difficult to ascertain if it is wholly crystalline or not. The phenocrysts make up about one-third of the rock. The following analysis was made of this rock.

		Duplicate.	Difference.	Average.
	%	%	%	%
SiO_2	69.49	69.46	0.03	69.47
Al_2O_3	11.74	11.72	0.02	11.73
Fe_2O_3	5.11	5.06	0.05	5.08
FeO	0.48	0.47	0.01	0.48
MgO	1.02	0.96	0.06	0.99
CaO	2.60	2.66	0.06	2.63
K_2O	5.40	5.29	0.11	5.34
Na_2O	3.45	3.47	0.02	3.46
H_2O @ 105° C	0.31	0.32	0.01	0.31
H_2O @ ig	1.28	1.28	0.00	1.28
MnO	present	present	not determined	
P_2O_5	present	present	not determined	
	100.88	100.69		100.77

The Basalt.—This rock occurs on the map Pl. 1 at the south end of Sing-ats'-e Ridge and on Whirlwind Mountain, shown on Pl. 2. Two thin sections were made of these rocks, but as they are not distinguishable from one another only one, No. 121, will be described. This rock on the freshest fracture is black, but on a long exposed surface it turns slightly red. At a distance it always appears black. Microscopically, feldspar and pyroxene make up the bulk of the rock. Opaque iron ore is relatively abundant and in irregular form. Translucent hematite of a reddish brown color is also recognizable. No olivine was with certainty recognized, and nearly half the rock is a ferro-magnesian mineral, which is an aluminous monoclinic pyroxene. It and the feldspar are apparently contemporaneous to some extent in crystallization; the pyroxene is often twinned, and has a nearly rectangular cleavage in sections normal to an optic axis, and has oblique extinction and irregular boundary. Its color is faint yellow or greenish, and its double refraction is strong, being blue and yellow of the second order, adjacent to quartz showing gray or grayish blue of the first order. Within the augite are needles of apatite and also iron oxide. The feldspar is of various sizes. The largest are about 1 mm. in length. Then there are sections nearly squared 0.5 mm., and the smallest feldspars are lath-shaped. The twinning of the larger phenocrysts exhibits rather broad and irregular stripes, and zonal growths are also pronounced. Oblique intergrowths are frequent, and many of the larger feldspars show resorption near the margin, and subsequent growth. This growth was more acid, having a lower relief and different extinction. The margin occasionally contains granular inclusions agreeing quite well with the augite, which would seem to indicate that it continued to crystallize up to a late date, which may be as late as, or subsequent to, the period of effusion. As for the phenocrysts of feldspar, a last attack is also noticeable on their margin; but not so on the small, lath-shaped ones, which may have grown in part at the expense of the more acid exterior of the larger ones. No glass was recognizable. Where alteration has taken place the plagioclase shows no calcite. But it is thought this agrees with what has usually been observed, that even should the plagioclase contains more calcium, calcite does not seem to form as readily as in the less basic members of the series. The absence of isotropic glass and a fluidal arrangement of the lath-feldspars seem to indicate the ability to crystalize at a comparatively low temperature. It may be remembered in this connection the apparent sheet like appearance of this lava.

The Schists.—Nos. 168*a* and 168*b* are samples of the schists shown on Sing-ats'-e Ridge near the southern end, as may be seen on the map Pl. 1. The grain of the schist is variable and the slides differ but a little. Biotite and quartz, and occasionally some small areas of sericitized feldspar may be seen through them. Slide 168*c* is from the schistoid dyke which is contained within this area, and which was mentioned as containing disseminated sulphides of iron and copper. It differs not essentially from the other two. In slide 168*b* the biotite is somewhat decomposed to epidote and chlorite near the feldspathic areas within the slide.

SEQUENCE OF THE IGNEOUS ROCKS.

The relative ages of the igneous rocks are granite, granite-porphyry, porphyrite, hornblende andesite, rhyolite, later andesite, and basalt, the relation of the last two not being determined.

Of the lavas, two were traced to points of exit and two were not. The hornblende andesite and the rhyolite were found in dykes as well as distributed on the surface, but the basaltic and latter andesitic rocks were not found in any sort of vent. This does not signify, however, that their points of exit are greatly distant, but perhaps that the writer's acquaintance with them is less.

THE ORE DEPOSITS.

The deposits of value carry copper and gold, but the two metals are not associated with one another in pay values. The richest copper deposits carry no gold, except perhaps as a trace, though occasionally a gold bearing vein contains copper, but not in values sufficient to warrant treating the ore for that metal alone.

Geology of the Deposits. It has been stated in considering the general geology of the region that the mineral veins are conformable to either one or the other of the main structural features the region, and such being the case, it would seem that they were consequent upon the inauguration of these systems, but it is not to be inferred that they were formed subsequently to all the structural features. In fact, there seems to be very positive evidence that they preceded the present topography, which stands as a record of the later stages of deformation. In some instances there are a few veins that do not conform to either system.

That the mineral veins have preceded the present topography seems quite clear, and this is thought to be so for two principal reasons, which are, the absence of the veins from the rhyolite and the fact that the veins often reach to the highest summits. The latter condition would indicate that there is not now sufficient hydrostatic head under present conditions of surface configuration to bring the solutions from which the veins were formed to their present height. It may be remembered in connection with the first of these reasons that previous to the advent of the rhyolite the region was reduced to one of tolerably low relief. This evidently indicates that the vein formation was not active at the surface, and it was not until the later Tertiary, when the present ranges had been lifted and erosion had begun its work of uncovering them, that they became exposed.

The period of formation of the veins closed with the making of the present mountains in the Tertiary, but when it began is not so clear. Most likely it was after the effusion of the early andesite, for in one instance an andesite dyke forms one wall of a vein. It appears that no andesite remains residual near the metamorphics in which the strongest deposits of copper occur.

The Deposits in Particular.—In a few instances the mining has progressed beyond the prospect stage. At the Ludwig Copper Mine a depth of about four hundred feet has been reached. The ore occurs in chambers in limestone. These chambers when taken together occur each more or less below the other, and when considered as a whole the idea of an ore chute nearly expresses their character. The chambers are along the contact between the iron ore deposit and limestone, which two occur as a simple outcrop having considerable length and a width of less than a hundred feet. They do not meet squarely in this outcrop, but somewhat diagonally, hence there is a longer contact zone for the chutes. The rest of the country rock is granitic. The ores are sulphide, oxide and carbonate. At the Douglas Mine the ore is chalcopyrite and chalcocite; the gangue is garnetiferous. About half of the ore is sulphide. It was apparently along the lines of fracture that the ore solutions found their way. The country rock is in part almost wholly garnet and in part granitic; with small areas of limestone overlain. At the Blue Stone Mine the country rock is an almost entirely altered limestone. It is perhaps more than half epidote, and presents in the hand-specimen a pale greenish gray color. This mass has been more or less fractured and refilled with calcite, in which the chalcopyrite is imbedded. The chalcopyrite is usually idiomorphic, at least it usually has one or two well formed faces. The rifts containing the ore betray some parallelism. The mine was named from a deposit of chalcanthite (blue-stone) which occurs near the surface. Farther south on this same ridge is the McConell Copper Mine, where ore occurs mostly as an oxide. Oxidation has probably extended deeper there than any of the places thus far mentioned. Near this mine are several prospects, which usually are near a contact of limestone and granite. The deposits so far mentioned are all in or adjacent to the belt of schist. One reef of schist of a dark color, which is thus in contrast to the rest of the surrounding schist, crosses the summit transversely. In it there was found disseminated sulphides of copper and iron. The reef was supposed, on account of its strike and width, to be a dyke which had suffered along with the rest of the rocks the dynamic action which produced the schists. Sulphide was also found near the grano-porphyry where it had been involved in the metamorphic action, but the sulphide did not appear to be so much disseminated as in the case of the dark reef.

Farther south of the McConell Mine, and off the map Pl. 1, gold occurs, and it also occurs in the Mason Pass, to the north. There is also mineralization to some extent northeast of the Blue Stone Mine, in the low hills near the west side of the river. East of the river, near the eastern border of the map Pl. 1, are several veins of copper. They have a very definite strike and dip, and are transverse to the summit of the ridges, and they occur along faults. There is not apparent the same amount of replacement of the wall rock or corrosion of the included breccia as in the case of the Ludwig and Douglas mines. Of these eastern ledges the Blue Jay has been most prospected. The mineralization in this case is confined to a belt about two hundred feet wide along a fault. The ore, which at the surface is cuprite, occurs in cracks and fissures. The thin sections of the rock of this belt show more or less alteration of the rock and substitution of quartz which contains liquid inclusions. Sulphide ores make some appearance farther down in the prospect, and there has been considerable oxidation along the fault, and more particularly because it is vertical and in the bottom of a cañon. A hydrous copper phosphate, which the miners termed malachite, occurs in the mine, and from qualitative chemical tests made by the writer it appears to be libethenite; and from some goniometrical measurements made by W. T. Schaller of the United States Geological Survey it exhibits a few new forms. Also of some interest is the formation of chalcanthite since the mining began. It appears to have formed in consequence of the steam which was introduced in diamond drilling. The remainder of the ledges occur from two to six feet wide, and the ore is much oxidized and leached. In some of the microscopic slides of the ores that have not been mentioned a very intimate relation of epidote to chalcopyrite is noticeable. The epidote occurs quite irregularly in outline, and the chalcopyrite tends to inclose it. The latter usually shows one or more quite distinct faces. This would seem to indicate that the chalcopyrite ceased to crystallize after the epidote and before the calcite or the quartz. In this connection it may be well to mention some of the considerations of a petrographical character that guided the writer in the study of the ores and their occurrence.

There appears as a corollary to many of the contributions to the subject of the formation of mineral veins, with respect to their structure, that relative idiomorphism and chemical phase cannot be regarded as having exactly the same significance that they have in the case of the igneous rocks. Their significance depends upon a different set of conditions. The banded structure frequently seen is due to a change in the solutions while the fissure is being filled; and as the filling starts on the walls and extends by successive layers or bands toward the middle, each mineral composing the layers is formed against a previous surface, and hence must have on one side the form of that surface. The other sides may not be freely developed on account of interference due to the minerals being contemporaneously grown. This is comparable to the allotriomorphic structure in granitic rocks. The bands may not show successively any regularity of chemical phase; one may be more acid than the next, or may be capriciously either, thus not possessing the regularity of the Rosenbusch order of crystallization. The writer was enabled to exemplify these propositions at the Steamboat Springs, which are near. This occurrence, as is well known, is often cited as an instance of vein filling now in actual progress, and consequently is one from which many of the ideas in regard to vein filling, including those on the crystallization of vein minerals, were derived. Another very good instance also occurs at Bridgeport, Mono County, California, near the source of the East Walker. It appears to have passed so far unnoticed. Instead of quartz being the filling material, a variegated travertine is filling the fissures. It is shown at this place, in addition to what is shown at the Steamboat Springs, how a portion of a vein may be formed without being directly attached to a previous surface. Hence idiomorphism has been taken in the sense just described in the study of the ores.

An Occurrence of Native Copper.—One occurrence of native copper has been discovered. It is not extensive enough to have sufficient economic value to make the mining of it profitable, but a study of its origin was found to be of an economic worth. While the ore bodies themselves have been produced by aqueous solutions, this occurrence of native copper was produced by reduction due to the heat generated by subsequent dynamic action, and a close parallelism was thus found to smelting processes, and by chemical and microscopical investigation of the ore and rocks adjacent to the native metal many of the steps that have been taken in the reduction are revealed, with the result that several suggestions were obtained for the actual treatment of the ores, and thus an opportunity was offered for an improvement in the smelting formulas and some troublesome irregularities lessened.

University of California,
December, 1904.

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UNIVERSITY OF CALIFORNIA PUBLICATIONS
BULLETIN OF THE DEPARTMENT OF
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Vol. 4, No. 2, pp. 33-38, Pl. 5 ANDREW C. LAWSON, Editor

A PRIMITIVE ICHTHYOSAURIAN LIMB FROM THE MIDDLE TRIASSIC OF NEVADA.

BY

JOHN C. MERRIAM.

During the last summer an expedition from the University of California spent some weeks in searching for ichthyosaurian remains in the Middle Triassic limestones of Nevada. Both Mr. E. L. Furlong, who directed the work, and Mr. H. M. Evans, who accompanied him, discovered unexpectedly good material, which will make possible considerable advances in our knowledge of these very early forms.

The oldest known Ichthyosaurians of which more than isolated elements or very fragmentary material have been described are the Mixosaurs of the North Italian Triassic. They were obtained from beds which have been held to represent the upper portion of the Middle Triassic. The oldest American Ichthyosaurs of which more than the vertebrae have been described are the Shastasaurs and the accompanying types from the Upper Triassic of California. Up to this time the limbs and arches of the North American Middle Triassic forms have been known only from scattered bones, the description of which has been withheld until more satisfactory material should be obtained.

Among the specimens discovered this year is one which shows the anterior half of the vertebral column, one side of the pectoral arch complete, the first two segments of a pectoral limb, and nearly the entire skull. It was found in the Middle Triassic limestones of Cottonwood Cañon by Mr. H. M. Evans. As nearly as can be determined, these beds seem to be somewhat older than those from which the Mixosaurs of the Italian Trias have been obtained. From the limestone horizon exposed in Cottonwood Cañon two saurian species have been described by Leidy.* Both were founded upon portions of vertebrae neither the generic nor specific characters of which have yet been satisfactorily determined. The most common ichthyosaurian species in these beds shows a strong similarity to the imperfect specimens designated as *Cymbospondylus petrinus* by Leidy. The specimen described here is tentatively referred to that species.

The greater number of the Ichthyosaurians showing primitive limb structure which have been described up to this time have been very small forms, and a suggestion of doubt may reasonably have been entertained concerning the probability of large forms from the same beds showing these archaic characters to the same degree. The earlier representatives of most groups are small, and in such forms primitive characters appear frequently when they would not be present in larger members of the same group. It is, therefore, a matter of some significance that the specimen under consideration ranks among the larger Ichthyosaurs, the skull measuring at least a metre in length and the humerus 280 mm. in length.

The elements of the pectoral arch and the limb were found in nearly the position in which they are figured, Pl. 5, excepting the scapula, which had been partly inverted.

The *pectoral arch* differs from that of all ichthyosaurian genera heretofore described. The *coracoid* is sickle-shaped, with a convex anterior border and an acute posterior angle. A foramen of considerable size is situated a little in front of the proximal articulation. This element differs from the coracoid in *Mixosaurus* and in *Shastasaurus* in possessing a convex anterior border, while in both of the other genera the proximal end is narrowed or pedunculate and the anterior border concave in part. Excepting the presence of a distinct perforation, the form is much the same as in the coracoid of the recently described *Delphinosaurus*† from the Upper Triassic of California.

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*See Bull. Dept. Geol., Univ. Calif., Vol. 3, No. 4, p. 104.

†Am. Jour. Sci., Vol. 19, p. 24, Jan., 1905.

The *scapula* is very strongly curved laterally to accommodate itself to the curvature of the body. The anterior and posterior borders are broken somewhat and may have extended out into a hook on each side, as in most of the Triassic forms. The outer border is practically entire and is nearly straight, giving the element somewhat more of the form seen in the true Ichthyosaurs.

The *clavicle* is very large and heavy; much broader and more robust than in *Mixosaurus*. The median end appears to have a large facet for the *interclavicle*, but, strangely enough, that element has never yet been clearly seen in any of the numerous Ichthyosaurians obtained from the West-American Triassic.

Taken as a whole, the pectoral arch resembles that of *Delphinosaurus* more than it does that of any other form. As will appear later, these forms also show evidences of affinity in the structure of the extremities.

As much of the *pectoral limb* as is known shows more resemblance to the type seen in *Mixosaurus* than to any other form. The *humerus* is of much the same type as in *Mixosaurus*, but is if anything a little more slender. Of the two humeri figured by Repossi* the principal illustration (fig. 2) represents an extraordinarily long and narrow form. In the other specimen (fig. 1), as in still others, the humerus is almost as broad as it is long.†

The epipodial elements are relatively long, as in all of the earlier Ichthyosaurs, and the space between them is very broad. The *radius* is, so far as the writer is aware, the narrowest specimen known in the Ichthyosauria, and the constriction of the median or shaft portion is pronounced. The *ulna* shows the most primitive form known in this group, and at the same time presents certain rather peculiar characters. In all other Ichthyosaurs, excepting *Delphinosaurus*, the posterior border of the ulna is expanded and usually convex. In these two forms it is concave or notched, like the outer or anterior border of the radius; and

---

*Atti Soc. Ital. Sc. Nat., Vol. 41, Pl. 9, figs. 1 and 2.

†It would appear to the writer that Repossi's figure 4, Plate 9, loc. cit. represents a femur rather than a humerus. It has the form of the femur in other specimens and does not resemble any other described mixosaurian humerus.

the median portion of the ulna is drawn in from both sides, showing a true constriction. In *Delphinosaurus* this constriction appears somewhat stronger than in this specimen, but the ulna is much shorter and broader, and the first two segments of the limb are, in general, more specialized.

On both the proximal and distal ends of the ulna the thick, cartilage covered portion of the margin extends far back toward the middle of the posterior side. The thickened margins come so near to each other that the posterior notch is made quite narrow. At the distal end this part reaches around quite to the middle of the shaft, reminding one of the surface against which the pisiform rests in *Mixosaurus*. At the proximal end the surface makes a sharp turn, forming a face which looks as if it might have supported a small supernumerary bone.

With another specimen of the same type as that described above there is an element appearing to represent either a fibula or an ulna showing a very primitive form. The shaft is narrower and the articular surfaces of the two ends are not swung back as far is in the specimen figured here. If this is really an ulna, it represents a stage more primitive than that described above.

Unfortunately, we have no very definite evidence concerning the character of the phalanges in this species. With both this specimen and the one from which the simpler form of ulna was obtained, there are several rounded ossicles resembling carpals. It may be that they are really reduced phalanges which rested in cartilaginous pads as in *Baptanodon*. If this be true, the general primitiveness of the limb would be reduced by some degrees; even in that case, however, the fact that the propodial and epipodial segments of the limb had failed to adapt themselves perfectly, even when the manus had become specialized, would tend only to show more distinctly the influence of an ancestry in which locomotion by crawling or running was more common than by swimming.

As far as we know it, the type of limb found in this specimen is more primitive than any heretofore described. The humerus is hardly more slender than that of certain other Triassic forms, but is among the most slender known, and is not more abbreviated than that of ***Mixosaurus.*** In the epipodial region, where specialization of a high degree appears in the later members of the order, we find a structure which is somewhat more primitive than any which has previously been observed in the Ichthyosauria. This is a particularly significant fact, when it is noted that the beds in which this specimen was found are probably a little older than those from which we have obtained the most ancient known European specimens showing the limb structure.

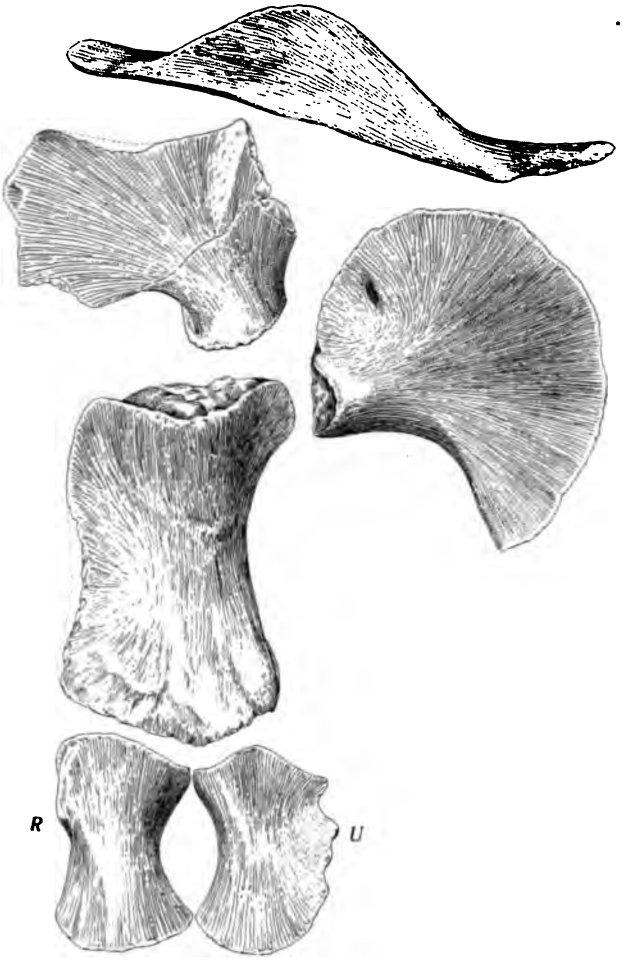
University of California.
February, 1905.

EXPLANATION OF PLATE.

Figure one-sixth natural size.

Cymbospondylus petrinus Leidy (?).

Pectoral arch, external side; anterior limb, inferior side. R, radius; U, ulna. The constriction of the ulna is immediately above the letter *U*. The broad, cartilage covered marginal faces of the ulna are discontinued suddenly at the upper and lower ends of the posterior emargination.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BULLETIN OF THE DEPARTMENT OF
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Vol. 4, No. 3, pp. 39-87, Pls. 6-7 ANDREW C. LAWSON, Editor

A GEOLOGICAL SECTION
OF THE
COAST RANGES NORTH OF THE BAY OF SAN FRANCISCO.

BY

VANCE C. OSMONT.

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INTRODUCTION.

The work of which this paper is the outcome was undertaken during the Fall of 1901, when the writer was a graduate student in geology at the University of California. The subject was suggested by Prof. Andrew C. Lawson, who rendered the writer invaluable assistance by his advice and personal supervision of the work, which has occupied the latter's spare time for the past three years. Acknowledgments are also due Dr. J. C. Merriam, Dr. Gidley, Dr. W. J. Sinclair, and C. E. Weaver for palaeontological aid.

No topographical maps of most of the area being available, county maps had to be used, and since these represent the topography poorly or not at all, it was not found feasible to map in the areal geology.

Two continuous cross-sections were made. Section AB starts at the south end of Bodega Peninsula, and runs in a northeast direction across Bodega Bay, through the towns of Bodega and Freestone, through the low hills east of Freestone, across the Laguna de Santa Rosa, and enters the broad valley of Santa Rosa a little north of Sebastopol; crosses the hills west of this valley about midway between Windsor and Mark West Creek; passes through Mark West Springs, crosses the watershed of that creek, passing about two miles north of the Petrified Forest; crosses Franz Valley and the high ridge east of it, and comes out at the low divide on the southwest flank of Mt. St. Helena, which separates Knights Valley from Napa Valley; thence it swings somewhat more to the north through Mt. St. Helena, and thence in an easterly direction across St. Helena Creek, passing a little north of the Oat Hill Quicksilver Mine, following approximately the boundary line between Napa and Lake Counties to Knoxville; continuing in this same general northeast direction, passing through the high ridge between Knoxville and the north end of Capay Valley at Rumsey, and thence through the low rolling foothills to the Sacramento Valley and Arbuckle, a distance in all of about eighty miles.

Section CD starts at a point about midway along the west shore of Point Reyes Peninsula, and runs northeast across Tomales Bay, continuing over the high ridge and rolling foothills for about fifteen miles, to the valley at Petaluma, thence, swinging a little more to the eastward, it passes through a low series of hills and crosses Sonoma Valley, some three miles south of the town of Sonoma; thence northeast to Napa City, continuing across Napa Valley, through the high ridge to the east to Wooden Valley and the upper end of Gordon Valley; through the prominent ridge separating the latter from Pleasant Valley, and thence through the rolling hills to the Sacramento Valley at Winters, a distance in all of about sixty-five miles.

Together the sections enclose an area of about fifteen hundred square miles, and since, as displayed in the graphical representations of the sections, there appears to be a well marked continuity of formations, it is believed that the geology is fairly typical of the Coast Ranges for a considerable distance north and south of the lines chosen.

The geological formations encountered in these sections range from pre-Franciscan to Pleistocene. They will be described in chronological order.

PRE-FRANCISCAN.

SEDIMENTARIES.

The oldest rocks known anywhere in the territory are a few small remnants of limestone and crystalline schists described by Anderson* in his paper on Point Reyes Peninsula. According to him, they consist of a "Marble similar to the white crystalline limestone of Montara Mountain and the limestone of Santa Cruz and the Santa Lucia Mountains." Associated with these limestones is quartzite, and at another place mica-schist and wollastonite schists are found overlying the granite.

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*Bull. Dept. Geol., Univ. Cal. Vol. 2, No. 5.

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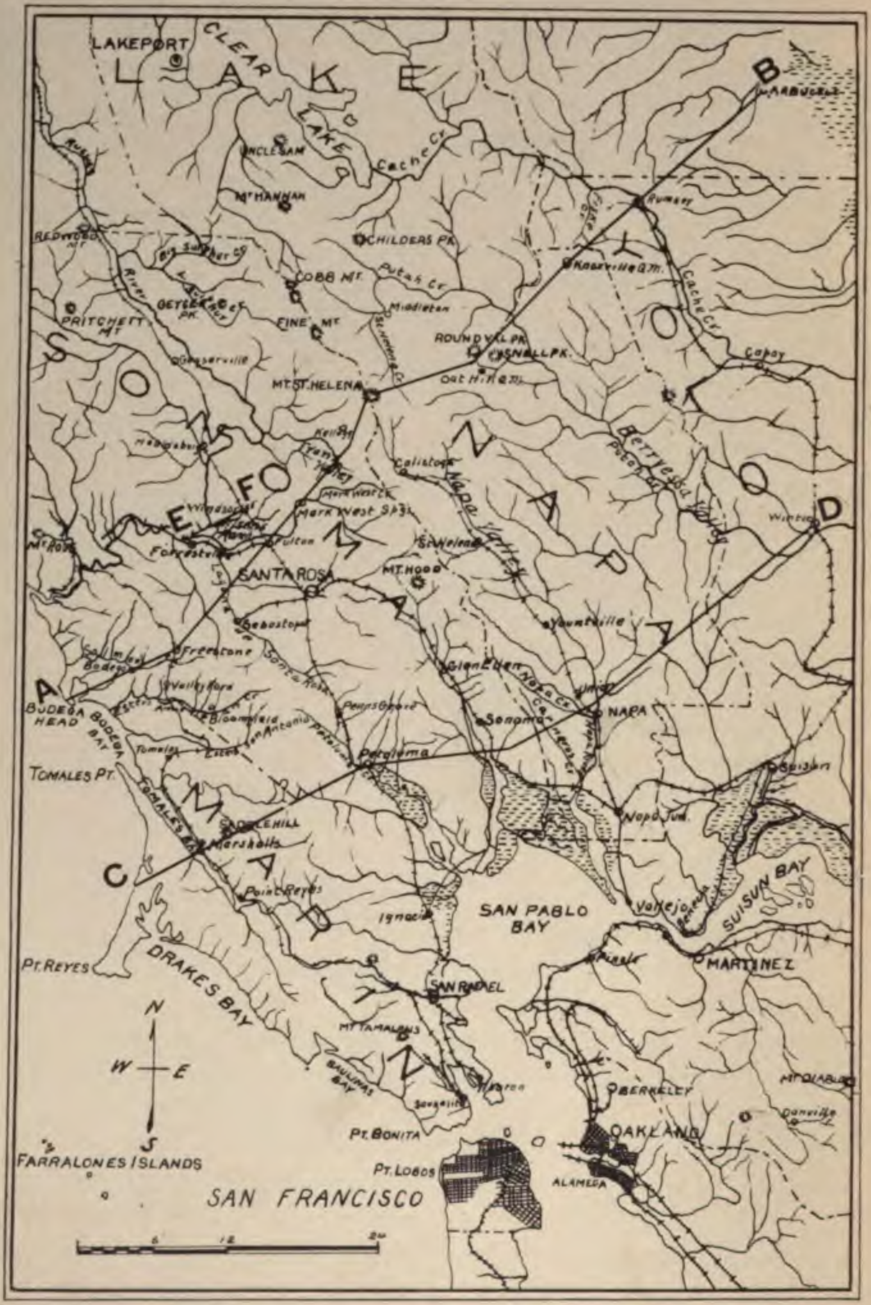

Index map of the Coast Ranges north of the Bay of San Francisco, showing the lines of Sections examined.

The age of this ancient series can only be guessed at from its relation to the granite which is intruded in it, as no palaeontological evidence is available. From considerations which will be mentioned later this granite is believed to be of post-Jurassic age. Hence the above mentioned strata cannot be later than Jurassic.

BODEGA DIORITE.

Bodega Peninsula is made up almost wholly of a biotite-diorite. Toward the north end of the peninsula this disappears from sight under æolian sands, and the coast line to the north of Salmon Creek is made up entirely of Franciscan sandstone. The east shore of Bodega Bay is entirely Franciscan.* To the south, however, Point Reyes Peninsula is composed very largely of this same diorite and granite, while a comparison with the geology of the coast to the south shows that this is only a northward extension of the plutonics occurring at Montara Mountain,† on San Francisco peninsula, and at Monterey, which are intruded in the old crystalline schists and limestones above mentioned.

FIELD ASPECTS.

The best exposures of the diorite occur on the ocean side of the Bodega Peninsula at the south end. Here it stands up in steep cliffs fifty to eighty feet high. It weathers deeply, and this makes it extremely difficult to get fresh specimens for examination. On account of the large amount of coarse mica present, it frequently shows a white honey-combed surface, resembling coral. Basic secretions are very abundant. They vary in size from a few inches up to six feet in length, and are usually lenticular in shape, having their longer dimensions more or less parallel and pointed in a westerly direction, suggesting pressure at right angles to their course. Dikes or veins of aplite, pegmatite and quartz occur. A very prominent pegmatite dike seven feet thick is exposed on the southeast side of the peninsula, while numerous smaller ones may be seen on the west shore. There is a general westerly trend also to these dikes. That a large amount of movement has taken place is abundantly shown by the sheared and crushed appearance of the rock in many places and numerous small faults displayed by the veins of quartz and aplite. So much movement indeed has affected these rocks as to render them utterly unfit for quarrying purposes. In this small area no remnant remains of the schists and limestones into which the granites are intruded at Point Reyes and to the South.

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*Anderson, Bull. Dept. Geol., Univ. Cal., Vol. 2, No. 5.

†Sketch of the Geol. of San Francisco Penin. Lawson, U. S. G. S., 15th Ann. Rpt.

PETROGRAPHY.

Two varieties of diorite occur on the peninsula—Biotite-diorite and Quartz-diorite. The first variety is very abundant, the second is scarce and represented only by a few loose fragments found near the north end of the bay.

Biotite-diorite.—Macroscopically it is a coarse grained holocrystalline rock, made up apparently of only two minerals in about equal proportions: a sugar-white feldspar and a dark green mica. The flakes of mica occur up to 6 mm. in length, and the ordinary length of the feldspar is about 4 mm.

Microscopically this rock is seen to consist of the essential minerals biotite and a soda-lime feldspar as determined below in about equal proportions, together with the accessory minerals apatite, magnetite and titanite, apatite being very abundant, and a large amount of decomposition products in the shape of kaolin and chlorite.

The twinning lamellae of the feldspars are very unequal in size, very coarse lamellae alternating with very fine ones. Single crystals, however, sometimes show fine, equal sized lamellae, together with a system of alternating coarse and fine ones. Albite twinning is the rule, though an additional pericline twinning was observed in some cases. Carlsbad twinning also occurs. Wavy extinction is very common and shows that the rock has been subjected to great strain.

By Michel Levy's statistical method a maximum angle of 20° was obtained on the albite twinning plane, corresponding to a feldspar of the composition between Ab_3 An_2 and Ab_4 An_3, or a medium basic andesine.

One section was found which could be utilized for M. Fouque's method for determining the feldspars on sections cut perpendicular to a bisectrix. This section gave an angle of 22° 16′

between the trace of the plane of the optic axes and (010). This value on the n_g curve corresponds to an acid labradorite.

Some of the rock was crushed and cleavage flakes of the feldspars selected. On examination under the microscope certain of these sections parallel to P, and showing albite lamallae which extinguish symmetrically, gave the extinction angle 5°. They also showed the emergence of a bisectrix very inclined to the section. If this angle is negative, it corresponds to a composition of $Ab_2 An_1$, according to Schuster. Sections showing no twinning lamellae and rhombic in form gave the following angles, 10°, 10°, 9½° and 6°, and extinguished in the acute angle of the rhomb. Hence, the angle is negative. $Ab_1 An_1$ corresponds to 5° 10′, while $Ab_1 An_3$ gives 17° 40′. Hence the determination points to a composition between $Ab_1 An_1$ and $Ab_1 An_2$.

In order to determine the specific gravity of the feldspars the crushed rock was put through an 80-mesh screen and caught on a 100-mesh. Thoulet's solution was used. At 2.652 about two-thirds of the feldspars remained suspended, though they all sank at 2.645. The temperature was 15½° C. On concentrating the solution the heavier feldspars became suspended at 2.675. The average specific gravity given by Rosenbusch-Iddings for andesine is 2.65, and of labradorite 2.69, hence this checks very well with the optical determinations. It also shows that quartz and orthoclase are absent.

The biotite presents no novel features. It is strongly pleochroic, the color for $\mathfrak{c}$ being dark reddish brown, $\mathfrak{b}$ dark reddish brown, and $\mathfrak{a}$ straw yellow to yellowish brown. The absorption is $\mathfrak{c} = \mathfrak{b} > \mathfrak{a}$. The biotite occurs in irregular plates with frayed edges, and the cleavage lamellae frequently are bent, due to shearing in the rock. It is usually altered around the edges to green chlorite. Magnetite occurs sparingly as inclusions, and occasionally titanite. Apatite is abundant, both included in the biotite and in the feldspar. A small amount of green hornblende was observed in one slide.

Quartz-Biotite Diorite.—Macroscopically this rock is seen to be a coarse grained holocrystalline rock, made up principally of white feldspar and a dark green mica, the feldspar forming about two-thirds of the bulk of the rock. The ferro-magnesian minerals occur in smaller flakes than in the mica-diorite above described, and the rock accordingly presents a harder surface to the weather. Its specific gravity is 2.731.

Microscopically the essential minerals are seen to be a soda-lime feldspar and biotite, a small amount of quartz and green hornblende and a little orthoclase. The accessory minerals are apatite and titanite, and the decomposition products kaolin paragonite and chlorite.

The feldspars are not very fresh, but are much clouded with kaolin and paragonite. Favorable striated sections gave by M. Levy's statistical method a maximum angle of 19°, indicating a medium basic andesine of a composition of about $Ab_3\ An_2$.

One section was found twinned on both the albite and the Carlsbad laws upon which M. Levy's method of concurrent angles was used. It gave the extinction angles 8° and 18°, indicating a section of andesine ($Ab_5\ An_3$).

Some of the feldspar sections are free from albite twinning, and look like orthoclase. Some of these are rhombic in shape, and three gave the angles — 12°, — 24°, and — 15°. These sections were probably cut parallel to (010). The negative sign precludes the possibility of orthoclase, as also the large angle 24°, orthoclase's maximum extinction angle being 21° against *c*.

Orthoclase is, however, probably present in small amount. Certain sections show inclusions of plagioclase with poikilitic structure, all the plagioclase inclusions extinguishing at the same time.

The biotite is identical with that of the mica-diorite above described. It contains little magnetite, its principal decomposition product being chlorite.

A small amount of green hornblende is present, which seems to have crystallized later than the biotite.

Chemical Analyses.—Two analyses of these rocks were made by the writer. No. I. is the biotite-diorite, and No. II is the quartz-biotite-diorite.

	No. I	No. II
SiO_2	58.44	63.12
Al_2O_3	17.06	16.13
Fe_2O_3	1.36	3.53
FeO	5.06	3.65
MgO	2.96	1.86
CaO	5.82	5.04
Na_2O	3.40	2.78
K_2O	2.84	1.08
$H_2O +$	2.12	.93
$H_2O -$	.38	.97
TiO_2	.15	trace
P_2O_5	1.41	.39
MnO	.50	.38
SrO	.....	.03
Total	101.50	99.89

Basic Secretions.—Macroscopically the basic secretions are fine grained dark rocks, containing, apparently, a much larger proportion of ferro-magnesian minerals, and being of greater specific gravity. They vary from medium to very fine grained.

Microscopically this rock is seen to be holocrystalline and fine grained, and made up of a plagioclase feldspar and green hornblende in about equal proportions.

The feldspar, though later than the hornblende, occurs in fairly well shaped lathes, almost always showing albite, and frequently also pericline and Carlsbad twinning. Several sections showing both albite and Carlsbad twinning, and cut perpendicular to (010), were recognized, and these were utilized for M. Levy's determination by concurrent angles. One section gave the angles 28½° and 14°, corresponding to a section of labradorite ($Ab_2\ An_1$) cut at an angle of 20° with (101). Another gave —25½° and —17½°, showing labradorite ($Ab_1\ An_1$), making an angle of 10° with (101).

Fouqué's method for sections, cut perpendicular to a bisectrix, gave an angle of 23° 15′, which corresponds to a medium basic labradorite on the n_g curve.

Acid Dikes.—Dikes of pegmatite, aplite and greisen are abundant, but no microscopical study was made of them. In the field the pegmatite was seen to be a very coarse grained rock made up of large crystals, up to more than an inch in diameter, of orthoclase quartz and muscovite. One section of the orthoclase afforded a beautiful illustration of cataclastic structure.

CORRELATION AND AGE.

The above described dioritic rocks of Bodega and Point Reyes peninsulas occupy but an insignificant part of the surface area of the territory under discussion, but from evidence at Point Reyes Peninsula, and elsewhere, it is probable that, together with what remains of the crystalline schists and limestones into which they are intruded, they underlie a large portion of the Coast Range. Their similarity, both chemically and mineralogically, to the granites of the Sierras, points to their being an outlier of the latter.

The evidence as to age of these rocks is not conclusive. If they are outliers of the Sierra granitics they are post-Jurassic, since Lindgren* and others have shown the latter to be intrusive in Jurassic strata. But we know that they lie unconformably below the Franciscan, and the age of the latter is still a moot question, some geologists not being prepared to admit so recent an age for it as lower Cretaceous.

FRANCISCAN.

Constituent Formations.—This series consists of the usual elements so well described by Lawson in his *Sketch of the Geology of San Francisco Peninsula.*† Briefly they consist of hard massive gray sandstone, weathering yellowish brown, known as "San Francisco sandstone," from its prevalence on that peninsula; soft gray shale interbedded with sandstone and occasional foraminiferal limestone or with radiolarian chert; massive radiolarian cherts in various colors from white to red; intrusive masses of basalt, having peculiar spheroidal forms, and known as "spheroidal basalt"; together with local variations in the forms of diabases, and even of gabbros; also pyroxenites and peridotites as intrusive dikes, sills and laccolites, usually almost entirely altered to large masses of serpentine; and lastly metamorphic contact-zones of glaucophane, actinolite, or mica-schists. It forms the basement upon which the later rocks of the Coast Ranges rest, and, wherever seen, shows evidence of having been repeatedly sheared and contorted by the many movements which have affected the latter.

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*U. S. G. S. Geologic Atlas, folio 66, Colfax, Cal.

†U. S. G. S., 15th Ann. Rpt.

It was not found practicable to work out in detail the structure of this formation, though with good maps and careful work it probably could be done. The whole series has been displayed in the sections as a unit.

Areal Distribution.—As regards its distribution within the territory under discussion, it is found in one small and four large areas. The most westerly of these forms a large part of the high ridge, following the coast line from Mt. Tamalpais northward through Marin County to the Russian River, and northward, except that part occupied by the granitics previously described. This Franciscan area varies in width from eight to fifteen miles, and forms a high coastal ridge, with a very even crest line, at an elevation of 1,000 to 1,200 feet above sea level. Being for the most part composed of rather hard rocks which resist erosion well, the cañon topography is frequently rugged, and the hillsides usually dotted with clumps of gray boulders of hard sandstone or chert, while trees seem to grow better upon the soil furnished by these rocks than upon that of the later formations. A trained eye can easily distinguish at a distance this formation from the smoother, more rounded contours and treeless aspect of the overlying Tertiary sedimentaries.

The second Franciscan area is a narrow strip about two miles wide, which forms the core of the range of hills between Santa Rosa and Napa valleys. Its extension north of a point about two miles north of the Petrified Forest, where section AB crosses, is not known to the writer, but it is found in the hills to the east of Rincon Valley, near Santa Rosa, but does not appear at the surface in section CD between Petaluma and Napa, it being covered over by Tertiary sediments and volcanics. At the waterworks, two miles east of Napa, a well sunk through the andesite encountered Franciscan chert at a depth of 1,500 feet.

The above mentioned area is worthy of note, since there is evidence to show that in the vicinity of the Petrified Forest at least, dry land existed during the period of volcanic disturbance, which will be shown presently inaugurated the later Pliocene. Section AB passes through this area, crossing it at a point about 1,300 feet above sea-level. Large pieces of petrified wood lie strewn along the flanks of this ridge where the pumicious tuff of the later Pliocene overlies the Franciscan, and on the same ridge, two miles to the south, large petrified redwoods, ten feet in diameter, and fully 500 years old, as shown by their rings, are lying on a Franciscan surface covered with pumicious tuff. Of some eight or ten trees observed, all lay with their roots pointed toward the northeast, the natural inference being that they were uprooted by a blast of air from some volcano to the northeast, and subsequently buried in the pumicious ashes in which they now lie. Another argument in favor of this ridge having been an elevated portion of the land during Pliocene times is the absence of andesite on both of its flanks, when two miles to the west, and five miles to the east, thick flows are found beneath the tuff.

A third small area of Franciscan is exposed on the southwest flank of Mt. St. Helena, low down on the divide between Knight's Valley and the upper end of Napa Valley. It is exposed here by the faulting which has tilted the block forming Mt. St. Helena, and is quite limited in extent. It is largely made up of serpentine.

A fourth area lies on the northeast flank of St. Helena, along St. Helena Creek at Mirabel and Middletown, extending northwest toward Cobb Mountain.

A fifth large area is near the last mentioned one. It occurs at the Oat Hill Quicksilver Mine, and extends to Knoxville, and occupies a large area west of Berryessa Valley.

Quicksilver Deposits.—The last two areas mentioned contain important deposits of cinnabar. These deposits occupy the western part of the two areas last mentioned in a general northwesterly and southeasterly direction along the eastern flank of Mt. St. Helena and its outliers, Twin Peaks and Round Valley Peak. The cinnabar deposits are invariably associated with serpentine, and usually occur at contacts between serpentine and sandstone, or crushed shale ("alta"), or rarely radiolarian chert. The veins are not true veins at all, but merely zones of silicified serpentine. The silica is in the form of opal, and has largely replaced the serpentine, the opal containing the cinnabar and metacinnabarite. The opalized areas are from a few feet to over two hundred feet in width, and very irregular in shape.

While the richest ore is usually at the contact between the opalized zones of serpentine and the sandstone or shale country rock, there are sometimes large bodies of low grade ore directly within the opalized area and many feet away from the contact. One instance* is known where the ore body consists of radiolarian chert, along a contact with serpentine, which has been filled with veinlets of opal carrying cinnabar.

Serpentine is very abundant throughout all the above mentioned areas, but it was not found practicable to map it. In some cases, especially near Knoxville, the masses of serpentine are more than a mile in width, their great size seeming to preclude the idea of their being dikes and to suggest that they must represent intrusive sills or laccolites.

SHASTA-CHICO.

The eastern portion of both sections is largely made up of Cretaceous shales and sandstones, most if not all of which probably belong to the lower Cretaceous or Knoxville series.†

Lithological Character.—This series consists of an enormous thickness of rather hard tawny yellowish sandstone, interbedded in monotonous succession with dark blue fissile shales, with occasional thin beds of dark blue limestone. The sandstone strata are usually less than two feet thick, and almost never more than ten, while their regular alternation with soft shale made the bedding very distinct and characteristic.

Stratigraphy.—While standing at high angles, these beds do not show any important faulting along either of the sections. From near Knoxville, where they appear to overlie a large laccolite of serpentine, they extend in unbroken succession with steep northeasterly dip, to the head of Capay Valley, at Rumsey, where they are covered by Tertiary gravels and sandstones. The average angle of dip from Knoxville to Rumsey cannot be less than 45°, which would give the series a thickness of four miles, and this does not represent the whole of the accumulation of sedimentary beds, since the upper limit is not exposed.

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*Noted by Lawson at the Great Western Quicksilver Mine, Napa County, and communicated verbally to the writer.

†Becker, Mon. XIII, U. S. G. S. Quicksilver Deposits of the Pacific Slope.

Eocene fossils are said to have been found near Arbuckle, but the locality is not known to the writer. Eocene strata may underlie the San Pablo(?) gravels and sandstones east of Capay Valley in the portion left blank on section AB.

As far as physical resemblances go, the Cretaceous exposed at Rumsey is exactly similar to that near Knoxville, with the possible difference that it may have a large proportion of sandstone and less shale. A magnificent section is exposed along Cache Creek across the strike of the beds for several miles, and the writer was not able to find any conglomerate beds or important changes in sedimentation to suggest the presence of Chico. From lack of palaeontological evidence, however, he has not ventured to call all this enormous accumulation of sediments Knoxville.

In Section CD an even greater thickness of Cretaceous sediments is shown between Pleasant Valley and Wooden Valley. This section represents certainly not less than five miles of strata, as it dips steeply to the northeast the whole distance, and shows no evidence of faulting. The Cretaceous of this section, as in section AB, disappears to the east at Pleasant Valley under late Tertiary gravels and sandstones, still with a northeasterly dip and a Knoxville appearance, and for similar reasons the whole series has been represented as Shasta-Chico. None of the massive, thick-bedded, cavernous sandstones so characteristic of the Eocene was observed. Becker* believed these strata to be of the same age as the Franciscan, considering the latter to be a metamorphosed phase of the former, in which the "prominent characteristics are the predominance of recrystallization, serpentinization and silicification."

Contacts between Knoxville and Franciscan at many places are now known, which show an unconformity existing between the two formations. No better illustration of this can be seen than at Berkeley. Here unmistakable Knoxville shales and sandstones containing *aucellae* may be seen along the lower slopes of the hills between East and North Berkeley, resting at moderate angles across the steeply pitching eroded edges of the various Franciscan members. In both the sections AB and CD the Knoxville rests on serpentine at Knoxville and at Wooden Valley. Wooden Valley is probably near the base of the Knoxville series, since at the lower end of Capell Valley, about three miles north of section BB, a bed of heavy conglomerate at least 100 feet thick occurs in the formation. This conglomerate seemed to be made up practically of Franciscan chert and old eruptives, and of course points to an erosion interval between the two formations.

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*Mon. XIII, U. S. G. S.

TEJON.

Yellow Sandstones on Carneros Creek.—Just east of Carneros Creek, about midway between Napa City and Sonoma, occurs an exposure of yellow to buff colored, massive sandstone, occasionally interbedded with buff colored shales. Apparently it dips beneath an exposure of blue San Pablo sandstone to the west, but no good exposures were observed to show the exact relation. The fossils found here were too imperfect for certain identification, but at Thompson's, two miles to the southeast, directly on the line of strike, in sandstone of identical appearance, C. E. Weaver has collected and determined the following Tejon species:

Leda gabbi Con.
Cardium breweri Gabb.
Meretrix uvasana Con.
Tapes conradiana Gabb.
Tellina hoffmani Gabb.

These strata extend only a mile or two north of this point, and are, so far as the writer is aware, the only strata of Eocene age represented in his territory.

MONTEREY.

Point Reyes Peninsula.—According to Anderson,* the surface of the orographic granite block of Point Reyes Peninsula is a shallow basin or trough, upon which rests a broad syncline made up of sandstone and the characteristic and well known bituminous shales. This formation occupies large areas to the south in Contra Costa County and southward, but has not been encountered by the writer in any other part of the area under discussion. At least 500 feet of these shales are represented at Point Reyes Peninsula.

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*Bull. Dept. Geol., Univ. of Cal., Vol. 2, No. 5.

SAN PABLO.

Blue Sandstone (Tuff) of Carneros Creek.—The only strata of undoubted San Pablo age occur as the core of the low range of hills between Sonoma and Petaluma. As illustrated in section CD, blue San Pablo sandstone occurs on Carneros Creek. It consists of the peculiar and very characteristic bluish to grayish, rather soft sandstone, exactly similar to that described* by Turner from Mt. Diablo and Corral Hollow, which is so common in the Coast Ranges to the south. It is really an impure andesitic tuff. It varies from a gray to deep blue in color, and from a coarse, massive rock to thin bedded shales. At the point where section CD crosses it, it dips at 50° to the southwest and is overlain unconformably by the Mark West andesite.

Age.—This formation is unique in appearance, and of widespread distribution throughout the Coast Ranges south of this territory, it also occurring on the west flank of the Sierras, where it is placed in the Ione formation. Even without the aid of fossils it can be unhesitatingly referred to the San Pablo, but at Carneros Creek a good bed of shells of this age exists. So far as the writer is aware, this is the most northerly locality in the Coast Ranges at which it has been encountered.

SAN PABLO (?).

In addition to the strata above described, there are certain others which are tentatively referred to the San Pablo. They certainly antedate the Pliocene lava flows of the Coast Ranges, which, it will be shown later probably belong to the later Pliocene. They consist of a variety of sandstones, shales and conglomerates, free from pebbles of volcanic rocks.

Pre-Volcanic Beds near Freestone.—Between Freestone and the mouth of Tomales bay and the town of Tomales these beds are well exposed, being here some 400 feet thick, and made up about as follows: At the base about 50 feet or more of a very coarse hard sandstone, approaching a conglomerate in texture, most of the grains being well water worn, and composed of chert or quartz; some 200 feet of sandy shales, usually yellow to buff in color, but sometimes variegated and interbedded with thin layers of Franciscan pebbles; and about 150 feet of massive yellow sandstone, sometimes firm, though usually soft, and containing layers and nodules of hard, dark gray limestone. These strata are lying almost horizontal in this vicinity, but farther east they dip gently to the northeast. At Freestone they are overlain conformably by the Sonoma tuff, which will be shown below to belong to the later Pliocene. Badly preserved marine shells, and two large indeterminate vertebrae were found in them.

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*Notes on some igneous, metamorphic and sedimentary rocks of the Coast Ranges of California. Jour. Geol., Vol. 6, No. 5, 1898.

Near the mouth of the Estero San Antonio, about three miles west of Valley Ford, is a good cliff-section in these sandstones which is fossiliferous. In this vicinity the writer found the following species:

Pecten caurinus Gould.
Natica sp.
Leda sp.
Machaera patula Dixon.
Solen sp.
Neptunea recurva Gate.
Crepidula grandis Midd.
Clementia subdiaphana Carpt.

Pre-Volcanic Beds at Trenton.—At Trenton a well sunk through the Sonoma Tuff into the sandstones beneath encountered a shell bed, but the only specimens procurable by the writer were casts, and indeterminable, though of a Merced appearance.

Pre-Volcanic Beds of Pleasant and Capay Valleys.—The strata along the Sacramento Valley slope of the range overlying the Cretaceous resemble very closely in character those above described. They consist of heavy bedded soft yellow to buff colored sandstones, soft pinkish to white fissile shales, and non-volcanic conglomerates made up of pebbles of Franciscan and Knoxville rocks. The principal difference is the frequent coarse character of the conglomerate, some of which is made up of pebbles six inches in diameter, and the inclusion of large angular boulders of Cretaceous sandstone. At Pleasant Valley the Sonoma Tuff of the later Pliocene overlies these sandstones, being conformable in dip, and in the same relation to them as at Freestone.

Age.—The question of the age of these strata cannot at present be conclusively settled. Gabb* referred the beds near Freestone doubtfully to the Miocene. *Pecten caurinus* is not supposed to extend back of the Pliocene, while *Clementia subdiaphana* is not known back of the Pliocene. These beds lie conformably beneath the Sonoma Tuff, which will be shown later is probably of late Pliocene age. But on the eastern side of Santa Rosa Valley a thick flow of andesite lies conformably beneath the tuff, with no intervening sedimentaries, while beneath the andesite is a marked unconformity separating the latter from fresh-water beds of probable Orindan age. Hence, since the marine sedimentaries near Freestone beneath the tuff are non-volcanic in their nature, they are tentatively referred by the writer to the San Pablo.

The sedimentaries beneath the Sonoma Tuff in Pleasant and Capay Valleys, while conformable in dip with the latter, are also non-volcanic in nature. That they are marine in deposition is shown by a bed of marine shells found in Pleasant Valley carrying numerous species of poorly preserved shells of the San Pablo appearance. These beds are also referred tentatively to the San Pablo.

ORINDAN (?).

Red Gravels of Santa Rosa Valley.—Certain strata of unknown age are here inserted, since they are certainly older than the Merced, and probably younger than the Cretaceous. They occur on the west side of Santa Rosa Valley, between Trenton and Healdsburg, where they form a low ridge of hills which, on account of their very red color, form a striking feature of the landscape. Where exposed in favorable places, as at landslides, it is found that this peculiar brick-red soil is derived from a formation which is characterized by being made up almost entirely of chert and sandstone of unmistakable Franciscan appearance. Sandstone predominates, about 60% being sandstone, 10% radiolarian chert, 5% quartzite, and 25% red clay, which holds it loosely together and gives it its striking color. There is a notable absence of volcanics, only a few pebbles of quartz-porphyry being seen. The gravel is of the average size of a pigeon's egg, with a small percentage of large pebbles up to four or five inches in diameter. No stratification is discernable, coarse and fine material being indiscriminately mixed. This formation lies unconformably upon the Franciscan, and beneath the Sonoma Tuff, seemingly unconformably. These gravels do not occur north of Healdsburg, so far as known, and have not been looked for by the writer south of Trenton, though they probably extend down to Forestville. On the east side of Santa Rosa Valley they have not been encountered. No fossils having been found in them. nothing definite can be said of their age, but for certain reasons, which will be shown in the chapter on correlation, they are supposed to correspond to the Orindan. Their lack of bedding points to their being of fluviatile origin, and they are probably quite local in occurrence.

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*Geol. Calif., pp. 83, 84.

Sedimentaries beneath Andesite on Petaluma Creek.—On the eastern side of Petaluma Valley, near Penn's Grove, on the headwaters of Petaluma Creek, are sandstones, shales and non-volcanic conglomerates of very similar appearance to those beneath the Sonoma Tuff at Freestone and Tomales. This formation is dipping at rather steep angles, 20° to 50°, and is overlain unconformably by Mark West Andesite. No Sonoma Tuff was observed. A fine grained clay shale yielded numerous good specimens of the rare fossil *Cyrena Californica* Gabb.

Lignitic Beds of Lawlor's Ranch.—About six miles southeast of the locality above described, and five miles east of Petaluma, on Lawlor's ranch, is a small bed of lignite in apparently these same strata. The beds are folded at angles up to 45°, and lie unconformably beneath the Mark West Andesite. A few indeterminable shells of fresh-water appearance, and several horse teeth have been found. The teeth were submitted to Dr. J. W. Gidley of the American Museum, who kindly furnishes the following information regarding them:

"The last upper molar, specimen No. 2251, belongs to a species of *Neohipparion* with a very progressive protocone. The lower molar, with the same number, is a different individual. This tooth has a peculiarly compressed appearance which does not agree with the ordinary full proportions of the upper molar. The little fold of enamel at the anterior external corner of the protoconid proves lower tooth, No. 2251, to belong to a genus more primitive than ***Equus***, but the small size of the fold indicates a very advanced stage for a Miocene form."

Lignitic Beds of Mark West Creek.—On Mark West Creek, about half a mile above the point where it enters Santa Rosa Valley, are lignitic beds which have been worked in a small way for coal. The lignite occurs in a diatomaceous shale which here underlies the Mark West andesite. The lignite deposit is small and unimportant, but interesting geologically, since these beds probably represent a fresh-water lake contemporaneous, if not connected, with that at Lawlor's Ranch.

Age.—Lignite is known to exist in these beds at two places, and, at the lignite beds of Lawlor's Ranch, horse teeth of late Miocene or early Pliocene age have been found, and imperfect casts of fresh-water shells. *Cyrena Californica* occurs abundantly on Petaluma Creek, and is known certainly from only one other locality, viz: Kirker's Pass, in the very uppermost part of the San Pablo section.*

Andesite intervenes between these beds and the Sonoma Tuff, and rests unconformably across the eroded edges of their strata. Hence they are considerably older than the tuff, and, as will be shown later, the latter is probably not later than early Merced. These beds are, therefore, referred tentatively to the Orindan, and will be discussed more fully later in the chapter on the correlation of the Neocene.

LATER PLIOCENE.

The formations observed by the writer in the region under discussion, and ascribed by him to the later Pliocene, make up a series conformable in dip, but containing erosion intervals. They consist of lava flows and sedimentaries; the former of two well marked characters, the one of intermediate acidity, the other acid; the latter partly of marine, and partly of lacustrine, fluviatile and aeolian deposition, but made up largely of volcanic detritus of intermediate acidity.

Starting at the base, the series consists of:

The Mark West Andesite, of varying thickness up to 1,500 feet.

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*Palaeontology of Cal. Gabb, Vol. II, p. 26, pl. 7, fig. 45.

The Sonoma Tuff, andesitic in character, and interbedded with thin flows of basalt, to the west with sandstones and volcanic conglomerates, and to the east with volcanic agglomerates and breccias. The maximum thickness of the tuff and agglomerate observed at any one place is 1,700 feet.

The Marine Beds of Wilson's Ranch, made up of soft, friable yellow sandstone and fine volcanic conglomerates of a thickness probably exceeding 2,000 feet, and carrying typical Merced fossils.

The St. Helena Rhyolite, of varying thickness up to 2,000 feet.

The maximum thickness observed for the whole series at any one place was about 4,000 feet, which does not take into account that portion of the rhyolite removed by erosion.

This series mantles indifferently over the older formations throughout the large portion of the area under discussion, and engaged most of the writer's attention. Hence it will be described in considerable detail.

MARK WEST ANDESITE.

Areal Distribution and Thickness.—The andesite flows in the central and northern portion of the area under discussion aggregate a great thickness, while to the south and west they thin out to mere sheets. Where exposed by a fault on the southwest slope of Mt. St. Helena they are over 1,500 feet thick, while the anticlinal fold just west of Mark West Springs shows a thickness of about 700 feet. At Napa City the waterworks well shows them to have a thickness of nearly 1,500 feet. Near Petaluma they thin down to about 100 feet, and somewhere under Santa Rosa Valley they run out to a thin edge, since they do not appear at all on its west side.

Structure.—They lie usually at small angles, mantling indifferently over the various older formation beneath them.

Age.—These andesites seem to be conformable in dip with the Sonoma Tuff above, but an erosion interval existed between the two, as shown by the numerous andesite pebbles included in the latter. The conformability of the dip with the Sonoma Tuff, the age of which, as will be shown later, is pretty certainly late Pliocene, together with its unconformable relation to the blue San

Pablo sandstone and to the supposed Orindan beds below, points to its being of late Pliocene age.

Petrography.—A specimen of this rock from beneath the Sonoma Tuff near the contact on the west limb of the anticline near Mark West Springs showed itself to be macroscopically a dark, heavy rock, varying from dark greenish black to brown in color, according to degree of weathering, and sufficiently coarse grained to enable the lath-shaped feldspars of the ground mass to be readily seen with the naked eye. Scattering phenocrysts of feldspar and of olivine occur up to 4 mm. in length.

Microscopically this rock is coarse in texture, consisting of a few large phenocrysts of labradorite and olivine scattered through a rather coarsely crystalline ground mass, made up chiefly of labradorite feldspar in well shaped laths almost universally twinned on the albite law, and rounded grains of augite, the structure being the common one called by Rosenbusch "Intersertal." The feldspar phenocrysts, measured by the common method of symmetrical extinctions on the albite twinning plane (101), gave a maximum extinction angle of 37.5°. According to Michel Levy, this angle corresponds to a labradorite of about the composition Ab_3 An_4. One crystal, rhombic in section, with good cleavages parallel to (001) and (100), and showing no twinning lamellae, was evidently cut parallel to the albite twinning plane (010). It gave an extinction angle measured against the trace of (001), of 22°. The extinction fell in the acute angle of the rhomb, making the sign negative. This corresponds to labradorite of a composition between Ab_3 An_4 and Ab_3 An_5.

Small crystals and grains of magnetite occur in some cases formed around the ends of the feldspar laths, never included in them. Hematite in flakes and irregular patches, and as a mere stain discoloring the feldspar, is very abundant. It seems to have come from some exterior source as an infiltration. Flow structure is very noticeable, the feldspar laths of the ground mass being drawn out in more or less parallel lines, and wrapped around the ends of the phenocrysts. A little glass is present.

A specimen from beneath the Sonoma Tuff on the east limb of the anticline near the contact at Mark West Springs is very similar in appearance to the rock above described from the west contact. It is dark greenish black, heavy rock, rather too coarsely crystalline fôr a basalt, with scattering phenocrysts of feldspar.

Microscopically it is also similar. It is somewhat fresher, and contains much less hematite. By Michel Levy's statistical method the feldspars gave a maximum angle of 43.5° This indicates a basic labradorite of a composition somewhat more basic than Ab_3 An_4 or nearly Ab_1 An_2. Augite occurs sparingly as phenocrysts up to .38 mm. in length. These crystals are rounded and corroded as though acted upon by the magma prior to consolidation. The abundant augite in the ground mass occurs in rounded grains lying between the laths of feldspar in the "Intersertal" structure of Rosenbusch. The feldspar lathes are short and stout, and invariably twinned on the albite law. The augite is of the usual lavendar gray color. It appears to be altering to chlorite of a dark green shade, which stains the rock freely. No olivine was observed in this slide. A slight flow structure was observed. No glass was recognized. A careful determination of the silica contents of this rock gave 65.13%.

A specimen from below the Sonoma Tuff on the southwest slope of Mt. St. Helena may be described as follows:

Macroscopically it is a dark grayish black rock, containing phenocrysts of lath-shaped feldspars and irregular greenish yellow decomposed augite crystals in a fine grained ground mass, which does not appear crystalline to the naked eye.

Microscopically this rock is made up of numerous large and small phenocrysts of feldspar and of augite embedded in a semicrystalline ground mass composed of numerous feldspar microlites embedded in glass. The feldspar phenocrysts are frequently well terminated, but the larger ones are usually broken and show wavy extinction. The maximum angle observed in sections showing symmetrical extinctions on (010) was 38°. This corresponds to a labradorite of about the composition Ab_3 An_5. The augite phenocrysts are worn, broken and corroded, and usually altered to chlorite and hematite. They were preceded by the magnetite which is found included in them. The feldspar is moulded on the augite. There is much magnetite dust in the glass of the ground mass, and also much chlorite, which stains the rock green in thin sections. This may have come frôm original augite grains in the ground mass. Flakes of hematite, and stains of the same, are abundant. Two crystals of ilmenite, altering to leucoxene, were observed. This rock contains 64.8% SiO_2. A finer grained rock from the same locality yielded 65.5% SiO_2. Similar lava extends from the hills on the east side of Santa Rosa Valley and extends west of Penn's Grove for about one mile. It rests unconformably upon the yellow sandstone and gravel which, near the headwaters of Petaluma Creek, some two miles northeast of Penn's Grove, contain the distinctive upper San Pablo fossil, *Cyrena Californica*. These andesites are supposed by the writer to be the same as those above described from Mark West Springs and Mt. St. Helena.

A specimen from one mile west of Penn's Grove station showed the following characteristics.

Macroscopically it is a heavy dark greenish gray rock of sufficiently coarse texture to enable the eye to recognize the crystallinity of the ground mass. Occasional small, well shaped phenocrysts of feldspar were observed, and small yellow spots, due apparently to the decomposition of the pyroxene, are numerous.

Microscopically this rock is seen to be rather coarsely crystalline in texture. The phenocrysts are very abundant, consisting of well shaped laths of feldspar and stocky prisms of augite, embedded in a crystalline ground mass of small feldspar laths and well shaped augite needles.

The feldspar gave a maximum extinction angle on a section cut perpendicular to (010) of 41°. This would indicate a feldspar somewhat more basic than Ab_3 An_4. The usual length of the labradorite phenocrysts is about .38 mm.

Augite is plentiful. While the needle-like crystals of the ground mass are well shaped, the large phenocrysts are usually badly corroded by the magma. The maximum length of these phenocrysts is about .5 mm. Much magnetite occurs as small cubes and octahedra, included principally in the augite. No olivine was observed, and no glass could be certainly determined in the ground mass. There is a distinct similarity between this rock and the ones described from the vicinity of Mark West Springs.

Another specimen from the same locality showed the following features:

Macroscopically it is a heavy dark greenish black rock, very similar in appearance to the last one described. It is evidently crystalline in character but with few phenocrysts showing to the naked eye.

Microscopically it is seen to be made up of numerous, but small, crystals of feldspar and pyroxene embedded in a ground mass of feldspar microlites and augite grains in the "Intersertal" structure of Rosenbusch. The maximum extinction angle of the feldspar phenocrysts was 41°, hence it is a medium labradorite. The largest crystals of feldspar observed measured 6 mm. in length, the largest of pyroxene 5 mm. These pyroxene phenocrysts proved to be orthorhombic. They were distinguished from the augite of the ground mass by their straight extinction, lower double refraction, and pleochroism. The latter, however, is very weak, and suggests enstatite. The color of the fresher crystals in ordinary light is a greenish lavender. The larger ones, however, are badly altered along the cleavage planes to hematite and a green mineral of weak double refraction, probably serpentine.

Augite is plentiful in the ground mass in small, short prisms and rounded grains. The rest of the mass seems to be made up of microlites of bytownite feldspar. No glass was certainly identified. Magnetite in cubes, and in grains scattered through the ground mass, is abundant. Also much serpentine and chlorite is present from the alteration of the pyroxenes.

The feldspars of the above described rocks vary from a medium to an acid labradorite, and this fact, taken in connection with the abundance of augite and occasional presence of olivine and enstatite, would lead one to call them basalts. But their silica contents is invariably high, averaging close to 65%. Hence they must be classed as pyroxene-andesites. The glass in the ground mass must evidently be very acid. Becker* probably referred to these rocks when he spoke of the "older andesites." He classed them as pyroxene-andesites. Similar rocks are described by Palache† from the Berkeley Hills.

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*Quicksilver Deposits of the Pacific Coast. Mon. XIII, U. S. G. S.

†The Berkeley Hills. Lawson and Palache. Bull. Dept. Geol., Univ. of Cal., Vol. 2, No. 12, p. 412.

SONOMA TUFF.

Following the andesite came enormous quantities of volcanic ashes. These ashes covered a large area, part of them falling upon dry land, part upon water, and part being washed down by the streams to form tuffs in the seas and lakes.

Character of the Tuff.—This tuff is a fragmental rock made up wholly of the volcanic material, and characterized by containing numerous fragments of pumice, in size from very small grains up to an inch or more in length. Two silica determinations made on the pumice, from two localities in Santa Rosa Valley, gave respectively 61% and 63% SiO_2. Hence it is andesitic in character.

The rock is usually very light in color and in weight, and, where well exposed, forms a conspicuous feature of the landscape. Certain fine grained varieties of it are easily worked into blocks, which make very good building stone where great strength is not required.

Areal Distribution and Thickness.—It is widely distributed in the Coast Ranges north of Mt. Diablo for at least 100 miles, and, as it is easily recognized, it was the writer's idea at one time to use it as a datum plane in an attempt to trace out the late Tertiary basin of the region. It was soon found, however, that this would take more time than was available, and the original plan of a continuous cross-section through a typical locality was resumed.

Good exposures of this tuff may be seen from Freestone southeast to Bloomfield, near Trenton and on the Russian River near the mouth of the Mark West Creek, in the lower foothills northeast of Windsor and near Mark West Springs as shown in Section AB. From here east to Calistoga, and beyond to the high ridge of Twin Peaks, there are large areas and immense thicknesses of it. As shown by Section CD, it is much thinner to the south. In fact, it was necessary at many places to exaggerate its thickness to show it at all on the section, since toward the southwest part of the area it is sometimes not more than ten or fifteen feet thick. From Mark West Creek to Franz Valley and at Twin Peaks southwest to Oat Hill Quicksilver Mine it has its greatest thickness, about 1,700 feet. Toward the west side of Santa Rosa

Valley it thins out very much. The great bodies above mentioned at Franz Valley and near Twin Peaks seem to be of the nature of agglomerate rather than tuff, containing an immense number of angular fragments of lava, mostly andesite. At the latter place fragments are sometimes encountered many tons in weight.

The Interbedded Sandstones and Conglomerates.—Toward the west, on both sides of Santa Rosa Valley, beds of the pumicious tuff, ten or fifteen feet thick, are interbedded with sandstone and gravel. The sandstone is usually a rather coarse, yellow, loosely compacted rock. The conglomerate is very distinctive. It is made up almost entirely of volcanics. The pebbles are mostly andesite, some appear to be basalt, and quite a large proportion is a white rhyolite which the writer has never encountered in place. Rhyolitic breccias, and occasional pebbles of Franciscan chert, glassy obsidian and petrified wood, also occur. Between Mark West Springs and the edge of the Santa Rosa Valley, along the line of Section AB, these gravels are very coarse, 75% being over two inches in diameter, and 10% over six inches. At this locality fully 1,900 feet of these buff colored sandstones and heavy gravels rest on top of about 200 feet of the pumicious tuff, but on the east limb of the anticline, and in the synclinal basin of Mark West Creek east of the springs, the same character of gravel is seen to be interbedded with considerable thicknesses of tuff, though at the base is nearly 600 feet of tuff free from sandstone and gravel. Thus the lower portion of the beds at this point are wholly tuffaceous, while the upper part contains no tuff at all, though the gravel is the same. On the east side of the anticline there is no line of demarcation between the tuff and the sandstone. Tuff seems to be interbedded with sandstone up to a considerable distance above the base, and then sandstone continues to the top. On Section AB two beds have been shown, one representing the tuff and the other the sandstone, but the line between the two is an arbitrary one, as the writer could not find it in the field, and is of the opinion that tuffs and sandstones belong to the same period of sedimentation.

Lava Flows within the Sonoma Tuff.—Intercallated with the tuff, on the east side of the anticline at Mark West Springs, about 300 feet from the base, is a forty foot flow of basalt. At Greeley's Ranch, three miles northeast of Windsor, this same flow seems to occur, resting on the Sonoma Tuff. At Mt. St. Helena, Sacro Cañon near Napa, and at other places flows of lava intercallated with the tuff and agglomerate were observed.

Petrography.—A specimen from Mark West Springs showed the following characteristics:

Macroscopically this is a dense dark greenish black rock, in which a few large phenocrysts of feldspar and of olivine can be seen with the naked eye. The ground mass does not appear to be crystalline.

Microscopically it is a very porphyritic rock, consisting of large phenocrysts of feldspar up to 2 mm. in length embedded in a micro-crystalline ground mass of small, well shaped feldspar microlites separated by augite prisms in the common intersertal structure. The microlites appear to be universally twinned, and a maximum angle was obtained on (010) of 33°. A large phenocryst also gave 33°. This maximum angle corresponds to a labradorite of a composition midway between Ab_3 An_4 and Ab_1 An_1. Olivine in prisms and rounded grains is rather abundant. The largest phenocryst observed was about 5 mm. in diameter. They are usually rounded on the corners and altered along the cracks to serpentine. The most characteristic feature of the structure is the sharp distinction between the two periods of consolidation. Large, well shaped crystals of labradorite enclosed in a micro-crystalline ground mass of well formed feldspar laths in intersertal structure with augite grains. Flow structure is beautifully developed, as shown by the disposition of the microlites around the phenocrysts. A little glass is present in the ground mass. A silica determination gave 43.06% SiO_2. The rock is a good example of an *Olivine-Basalt.*

Another specimen from Greeley's Rranch, about three miles northeast of Windsor, will be described. Here the hills have a thin capping of basalt resting on Sonoma Tuff and gravels. Structurally this basalt appears to the writer to correspond to the flow above described at Mark West Springs.

Macroscopically it is grayish black rock, quite scoriaceous, with many vesicles which have been subsequently filled with opal and iron oxides. The phenocrysts are numerous and easily discernable to the naked eye, some of them being 2 mm. in length. They appear to be wholly feldspar. The ground mass is unresoluble to the naked eye.

Microscopically it is strikingly similar to the rock described from Mark West Springs. The two periods of consolidation are even more sharply divided, and the movement of the magma between the two periods is still more clearly shown. The feldspars gave 35° as their maximum extinction angle, indicating a labradorite of composition near Ab_3 An_4. Large lath shaped labradorite phenocrysts were embedded in a microcrystalline ground mass made up of a multitude of very minute microlites of labradorite and grains of augite in intersertal structure. No olivine was observed. A small amount of brown glass is present, which seems to have come from some exterior source. This rock would be called ordinary basalt.

Age.—Near Freestone numerous casts of shells were found in this tuff, but they were not determinable, though they were certainly marine in character and resembled the shells of the Merced above. Its conformable relation to the Wilson Ranch beds suggests its being of lower Merced age.

MARINE BEDS OF WILSON'S RANCH.

Lithological Character.—Near Wilson's Ranch, on the Russian River, some two miles above the mouth of Mark West Creek and lying conformably upon about 100 feet of Sonoma Tuff interbedded with coarse volcanic conglomerate and yellow sandstone, is a formation of heavy-bedded, friable yellow to buff colored sandstone, interbedded occasionally with fine volcanic conglomerate and beds of shells. It dips gently toward the Santa Rosa Valley, and is of unknown thickness, but is probably upward of 2,000 feet. On account of their soft, friable nature these beds weather in characteristic "Bad Land" forms.

Areal Distribution.—These beds extend along the east bank of the Russian River, apparently about half way to Healdsburg, dipping to the east and disappearing under the valley alluvium. On the eastern side of the Santa Rosa Valley, exposed along the foothills north of Mark West Creek, are sandstones of very similar appearance and weathering, but interbedded with much coarser gravels. They show no fossil beds, and seem to be of the nature of a river deposit. They lie conformably above the Sonoma Tuff and are dipping toward to the valley to the west. At Freestone, conformably above the Sonoma Tuff and lying almost horizontally, is a yellow sandstone of almost identical character to that at Wilson's Ranch. It extends northward toward Trenton and dips gently toward the northeast. No fossils were found in it. In Petaluma is a small exposure which may be a remnant of these beds.

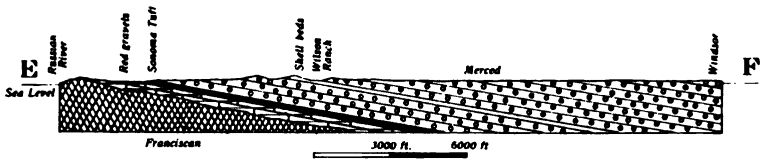

FIG. 1.

Section from the Russian River to Windsor, across the Santa Rosa Valley, showing the stratigraphic relations of the Merced, Sonoma Tuff, Red Gravels, and Franciscan, and the position of the Merced shell beds at Wilson's Ranch.

The only good shell beds observed in this formation are located at Wilson's Ranch, on the east bank of Russian River some three miles southwest of Windsor and one mile north of Trenton. They occur about 1,000 feet above the Sonoma Tuff. The writer made several trips to this locality and collected a number of fossils, which he was enabled to identify as follows:

Tapes staleyi Gabb.
Macoma nasuta Con.
Standella nasuta (?) Gld.
Schizothoerus Nuttali Con.
Natica clausa Brod. and Sby.
Natica lewisii Gld.
Olivella biplicata Sby.
Chrysodomus tabulatus Baird.
Arca trilineata Con.
Nassa near *californiana* Con.
Cardium corbis Martyn.
Crepidula grandis (?) Midd.
Purpura saxicola Val.

Solen sp.

Pleurotoma sp.

Age and Correlation.—The similarity of the above list with the species which occur in the Seven Mile Beach section and those of Capitola, Half Moon Bay and the Scotia section of Humboldt County is at once apparent and fixes the age of these beds as Merced. The abundance of *arca trilineata* points to their being of about the horizon represented at Capitola.

The physical appearance of these sandstones also strongly suggests the Merced and Wild Cat series. They are soft and friable and easily weather in the characteristic "Bad Land" forms so commonly seen in the above mentioned formations.

ST. HELENA RHYOLITE.

Field Aspects, Areal Distribution and Thickness.—Lying conformably above the tuff are thick flows of lava of a very much more acid composition than that below. The section at Mt. St. Helena shows a thickness of fully 2,000 feet, not taking erosion into account, all of which is of the same general character, being a very light colored trachytic looking rock which readily weathers and is conspicuous by reason of its lack of ferromagnesian phenocrysts. Lava of the same character forms the crest of the high ridge east of Napa City, occurring in great thickness and dipping toward the valley, so that a thin layer of it still remains in the valley itself, just east of the town, capping the tuff and andesite. It also forms the highest member in the country between Napa and Sonoma, and between Sonoma and Petaluma, the latter place being the farthest west it has been found.

Petrography.—A specimen from the top of Mt. St. Helena showed the following characteristics.

Macroscopically it is a very light colored, almost white, rock, occasionally slightly reddish from iron stains, notably lacking in ferromagnesian minerals. It has a rough, trachytic-like surface. Numerous large, glassy feldspar phenocrysts can be seen, but no quartz. The ground mass appears to be noncrystalline.

Microscopically this rock is seen to consist of numerous rather poorly formed phenocrysts of potash and soda-lime feldspars enclosed in a fine grained ground mass composed mostly of glass. No ferromagnesian mineral is present, the only iron bearing mineral being occasional cubes of magnetite and flakes of hematite, the feldspars frequently being stained with the latter. The most abundant phenocryst is sanidine. Its frequent straight extinction and absence of repeated twinning served to distinguish it from the plagioclase present. It is very abundant, and sometimes occurs in well terminated crystals, but usually in broken fragments, frequently badly kaolinized. A relatively small amount of plagioclase occurs, of which the highest extinction angle observed on (010) was 10.5°. This would indicate either albite or oligoclase. The ground mass is very fine grained, and under the high power is seen to be composed of minute fragments of feldspar, apparently sanidine, intimately mixed with unindividualized glass.

Determined solely by its optical properties, this rock would be called a trachyte, since no quartz phenocrysts were observed. A silicia determination, however, showed it to contain 72.13 SiO_2. Hence it is classed as a *Rhyolite.* A similar rock from above the Sonoma Tuff on the west side of Wooden Valley, Napa County, yielded 72.36% SiO_2.

A specimen from a quarry in Sarco cañon, east of Napa City, shows the following features:

Macroscopically it is a nearly pure white rock, with a rough, sugary fracture and conspicuous absence of ferromagnesian minerals. The only colored constituents are small specks of hematite. Large phenocrysts of feldspar are visible to the eye, but no quartz. It has a roughly laminated appearance.

Microscopically it shows large phenocrysts of sanidine embedded in a micro-crystalline ground mass of a very acid plagioclase in well shaped microlites in simple twins. These laths have a well defined parallel arrangement, due to flowage of the magma. Scattered octahedra of magnetite are present, and a large amount of hematite dust, which by its arrangement serves to bring out the flow structure more clearly. No primary quartz was observed, but a small amount of secondary quartz was seen. This rock is very similar to that at Mt. St. Helena, and the writer has classed it as rhyolite.

The area east of Petaluma is largely composed of St. Helena rhyolite, and at certain places very laminated phases of it occur. Near Kelly's Ranch, six miles southeast of Petaluma, a beautiful laminated variety occurs.

Macroscopically this is a light colored, almost white rock, marked with numerous parallel reddish lines giving it a beautiful laminated appearance.

Microscopically it is seen to be composed of sanidine and quartz phenocrysts with no definite crystal boundaries, which have been drawn out into parallel lines by the movement of the molten magma. They were rolled over and over, and fractured and rounded before the magma finally solidified as a glass around them. The ground mass now folds around the phenocrysts and broken fragments in eye-shaped form, the flow structure being beautifully brought out by numerous wavy parallel lines of hematite dust. It contains 72.24% SiO_2. This rock is an excellent example of a banded rhyolite.

Similar banded rhyolites have recently been observed by Ch. E. Weaver farther to the south, on the ridge between Petaluma and Napa, and at Glen Ellen. In both cases they lie above the tuff.

Becker's "Asperite."—Becker* refers to these rocks as follows: "Extensive areas of andesite occur to the southward of Clear Lake. Mt. Cobb and Mt. St. Helena and, indeed, a great part of the range of which the latter forms the culminating peak, known as the Mayacmas Mountains, are andesitic. The andesites extend down almost continuously to within a few miles of Vallejo, at the head of the Bay of San Francisco. . . . Both dense andesites of the earlier type and the asperites are represented. . . . The andesite is for the most part glassy when fresh, though asperites are also found. This rock constituted the greater part of the mass of St. Helena, and covers large areas to the north, east and southeast of that mountain. The summit of Mt. Cobb is also andesitic. Tuffaceous forms of andesite, usually much decomposed, are also abundant, especially to the south."

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*Quicksilver Deposits of the Pacific Coast, Mon. XIII, U. S. G. S.

From the above statement, and his petrographical descriptions, it appears that his asperites correspond to the St. Helena rhyolite, and his older andesites to the Mark West andesite of the present writer, while his andesitic tuff is the Sonoma Tuff, which is extensively developed just southwest of the Oat Hill Quicksilver Mine.

AGE OF THE ABOVE SERIES.

In the excellent section near Freestone the Sonoma Tuff, containing marine shells, is resting horizontally, and strictly conformably, upon marine sandstones and conglomerates non-volcanic in their nature and containing shells referred doubtfully by Gabb to the late Miocene. On the eastern side of Santa Rosa Valley, however, near Mark West Creek, some 700 feet of Mark West andesite occurs, directly underneath and conformable with the tuff, while to the south, on the head-waters of Petaluma Creek. this andesite may be seen resting unconformably across the eroded edges of nonvolcanic sandstones and conglomerates very similar in appearance to that near Freestone, but of fresh-water origin and containing a typical upper San Pablo fossil, *Cyrena Californica.* In these latter strata also, at Lawlor's Ranch, horse-teeth very similar to those of the Orindan have been found, which Dr. Merriam refers tentatively to late Miocene. The Mark West andesite appears therefore to certainly be post-San Pablo, and probably post-Orindan in age.

At Rodeo, on San Pablo Bay, occurs an exposure of pumiceous tuff indistinguishable in appearance from that described above in the writer's territory. It rests conformably upon the typical San Pablo, but recently Dr. J. C. Merriam found horse-teeth and other vertebrate remains in it, showing it to be not older than Pliocene. Dr. J. W. Gidley kindly examined these horse-teeth, and reports as follows:

"Number 2142 is an upper molar of Protohippus."

On the west side of Santa Rosa Valley, along the Russian River, the Sonoma Tuff lies conformably beneath the Wilson Ranch Beds, which are certainly of Merced age, probably about the horizon represented by the Capitola section and the base of Seven Mile Beach section. The Sonoma Tuff is, therefore, pretty certainly of lower Merced age.

Beyond the fact that the St. Helena Rhyolite followed the Sonoma Tuff, the age of which is pretty well established, the writer has not been able to gain much evidence as to its age. It has not been observed in contact with the Wilson Ranch Beds, but is probably later in age, as the latter do not seem to carry any pebbles of this rock.

Becker* determined the lower limit of the age of this rhyolite, which he called "asperite," by the fact that it overlies fresh-water beds near Clear Lake, called by him the Cache Lake Beds, and referred doubtfully by Marsh, on the evidence of very fragmental vertebrate remains, to the late Pliocene. At every place where seen in contact with the tuff, with the possible exception of one locality in the edge of the foothills east of Sonoma, where the rhyolite may be lying across the eroded edges of the tuff, it appears to be strictly conformable in dip with the underlying tuff. These dips are frequently steep, and this fact, taken in connection with the topographical consideration that deep, wide valleys such as those of Santa Rosa, Sonoma and Napa have been formed subsequent to the folding of the rhyolite, and have cut through thousands of feet of it and deep into the underlying formations, makes it seem unlikely that the St. Helena rhyolite can be much later than the end of the Pliocene or, at most, the very early Quaternary.

THICKNESS.

The later Pliocene volcanic and sedimentary formations form a series, conformable in dip, of varying thickness, which is shown in the section at St. Helena to be at least 4,000 feet thick, leaving out of account the rhyolite removed by erosion. In Santa Rosa Valley, to the west, the marine sediments and fluviatile deposits are certainly not less than 2,000 feet thick, and the synclinal structure shown in Section AB at Santa Rosa Valley points to their being fully 3,000 feet. In most places the series is gently folded, mantling indifferently over the older formations, but in a few places near the axis of the range, notably near Franz Valley, the axes are steep and the folds numerous.

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*Mon. XIII, U. S. G. S.

CORRELATION OF THE NEOCENE STRATA.

It has been thought advisable to discuss in some detail the correlation of the various strata included in this paper between Monterey and Pleistocene.

Stated in tabular form and in descending order, the writer believes the Neocene of this territory to be made up as follows:

LATER PLIOCENE.	ST. HELENA RHYOLITE.		
	WILSON RANCH BEDS	West of Santa Rosa Valley: Sandstones and a small proportion of shales and fine *volcanic* conglomerate, marine fauna, *Arca trilineata*, etc.	East of Santa Rosa Valley: Sandstones, shales and a large proportion of coarse *volcanic* conglomerate. No fossils. Coarseness of gravel and close bedding indicating fluviatile origin.
	SONOMA TUFF	West of Santa Rosa Valley: Interbedded with rather coarse *volcanic* conglomerate and carrying casts of marine shells.	East side Santa Rosa Valley: Interbedded with heavy *volcanic* gravel and fluviatile in origin. East of Mark West Creek Basin: Interbedded with heavy *volcanic* agglomerates and largely of *aeolian* deposition.
	MARK WEST ANDESITE.		

UNCONFORMITY.

ORINDAN (?)	Sedimentaries of Petaluma Creek and Lignitic Beds of Lawlor's Ranch and Mark West Creek.	Sandstones, shales and *non-volcanic* conglomerates. *Fresh-water* fauna. *Neohipparion*, etc., and *Cyrena californica*.
SAN PABLO (?)	Pre-Volcanic Beds of Freestone, Trenton, Pleasant and Capay Valleys.	Sandstones, shales, and *non-volcanic* conglomerates. *Marine* fauna; *Clementia subdiaphana*. *Pecten caurinus*, etc.
SAN PABLO	Blue Sandstone (tuff) of Carneros Creek.	

When we try to correlate the different members above tabulated with well known formations in other localities we can at once refer the blue sandstone of Carneros Creek to the typical San Pablo of Kirker's Pass and the San Pablo Bay sections.

Also, we can safely correlate the Wilson Ranch beds with the typical Merced, with a strong probability, from the abundance of *arca trilineata,* that it belongs to about the horizon represented at Capitola. Becker's Cache Lake beds may be their fresh-water equivalent.

Now, it was thought in the beginning of this work, that the very characteristic pumiceous tuff called in this paper the Sonoma Tuff would serve as a datum-plane to connect the formations encountered with those of Contra Costa County, for pumiceous tuff is extensively developed throughout the Mt. Diablo region. Unfortunately, a difficulty has arisen, which will now be discussed. In the Contra Costa district a pumiceous tuff identical in appearance to that found in the writer's territory exists at the base, or interbedded near the base, of an extensive fresh-water deposit, called by Lawson the Orindan, and described as being a "Thick formation of pebbly conglomerate, feebly coherent sandstones, thin beds of volcanic tuff generally decomposed and of a dark brownish color, beds of blue and slate colored clay containing fresh-water ostracods, sandstones containing ostracods and molluscs, and occasional patches of lava of quite limited extent intercallated (?) with sedimentary beds. No marine organisms have been found in any part of the beds."

This Orindan formation mantles indifferently over the blue San Pablo, the Monterey and the older rocks, but, save for the pumiceous tuff near its base, it is *nonvolcanic* in its nature, and precedes all the lava flows of the Berkeley Hills. In its gravels certain vertebrate remains have been found by Lawson, Merriam and Sinclair, the most important of which are horse-teeth. These were referred to Dr. Gidley, who reports upon them as follows:

"Number 1324 is a very interesting tooth as it is indistinguishable from *Hipparion richthofeni,* a species from Eastern China. It is possible it may represent a species of true *Hipparion.* Number 1323 is an upper molar of a smaller species, probably *Neohipparion.*". *Hipparion richthofeni* is reported from the lower Pliocene.

The above evidence points to these gravels being of late Miocene or early Pliocene age. Certainly they are later than the marine blue San Pablo, and older than the Merced. At Rodeo, however, is a syncline of pumiceous tuff resting conformably on typical San Pablo strata, and of identical appearance to that beneath the Orindan gravels at Pinole and southward, and in this tuff Dr. Merriam recently found horse-teeth of more recent type than those from the Orindan gravels. He thinks that they cannot be older than Pliocene. No gravels occur with the tuff at Rodeo.

Proceeding on this assumption, therefore, the writer correlates the fresh-water deposits beneath the Mark West Andesite on the eastern side of Santa Rosa Valley with the Orindan.

If the above correlation is correct, it is evident that the gap between San Pablo and Merced is somewhat bridged over, but the writer thinks it premature to attempt at this time any correlation of his intervening formations with those of the Berkeley Hills, such as the Berkeleyan.

QUATERNARY.

It was not found possible with the scale used to adequately represent the Quaternary deposits. All of the streams of the territory under discussion show terraces, usually covered with flood-plain deposits, while the shores of the bays and estuaries frequently show wave-cut terraces covered with gravels and sands.

Tomales Bay Deposits.—According to Anderson, the Pleistocene deposits in the vicinity of Tomales Bay consist of "Coarse arkose detritus with an indistinct horizontal stratification. They are found generally in the larger depressions of the peninsula, and range in elevation from 500 feet downward. They form a series of low, broad hills, extending along the middle of the valley near Olema, and occur at intervals upon both shores of Tomales Bay, forming there a system of low, bench-like terraces below 200 feet in height. West of the main ridge they are found in occasional patches around the flanks of the hills at the head of Drake's Estero and north of Abbott's Lagoon."

Bodega Bay Deposits.—At Bodega Bay similar deposits to those mentioned by Anderson occur on both sides of the bay, but only in small patches, most of them having been removed by erosion. Near Bodega Point on the bay side is a remnant resting upon a wave-cut shelf just about at high-water mark and extending up to 113 feet above the same, consisting principally of diorite sands, and occasional pebbles showing very indistinct horizontal stratification and cross-bedding. On the ocean side of the peninsula occasional still smaller patches, some twenty to thirty feet thick, may be seen resting upon a very evenly worn diorite surface, which at a point about three miles south of the mouth of Salmon Creek dips gently toward the north and passes under the beach and aeolian sands. On the eastern side of the bay is a broad, flat terrace, about one-quarter of a mile in width and some seventy-five to ninety feet above sea level at its back. In most places only a thin veneer of gravel covers this terrace, but at one point on shore, at the north end of the bay, a remnant of gravel some fifty feet thick is resting upon the worn Franciscan surface, which is here only some twenty feet above sea level. It is made up chiefly of Franciscan pebbles, and loosely coherent sands showing cross-bedding. It has been somewhat distorted, dipping slightly to the north.

Flood Plain Deposits.—All the larger valleys of this portion of the Coast Ranges, such as Santa Rosa, Sonoma and Napa Valley, and the great Sacramento Valley itself, show extensive flood-plain deposits extending up to an elevation many feet above the present level of the streams. These terraces are usually covered with, or largely made up of, ill-assorted heterogeneous material, representing all the rocks of the immediate neighborhood. In the case of the large streams like the Russian River, nearly all the rocks of the whole area described in this paper are represented. Usually the stratification is very irregular and indistinct, cross-bedding being common. Good exposures may be seen along the railroad cuttings at many places in Santa Rosa Valley. Here the material is usually made up of a very light colored, almost white, incoherent, silt-like sand, with much moderately fine gravel containing a great variety of well worn pebbles, consisting of Franciscan cherts, quartz, sandstones and intrusives, Knoxville sandstone, and a large proportion of Tertiary volcanics, conspicuous among which is a white rhyolite.

STRUCTURE.

FOLDING OF THE MERCED.

It may be concluded that the folding of this series inaugurated the present Coast Ranges, and probably took place not earlier than the very end of the Pliocene. Lawson's work on the Peninsula of San Francisco shows that the Merced beds to the very top at Seven Mile Beach are sharply tilted, while resting unconformably upon these are strata of undoubted Pleistocene age. This would seem to fix the uplift that disturbed the Merced at the very close of Pliocene times. Recent work by Arnold* points to the possibility of the upper portion of the Merced beds at Seven Mile Beach being Pleistocene in age. If this is true, the uplift did not take place until the Quaternary was somewhat advanced. In the present writer's field the St. Helena Rhyolite is folded with the sedimentaries and volcanics beneath it, and the upper portion of these sediments contains shells of Merced age. Furthermore, these rhyolites ("asperites") overlie the Cache Lake beds of Becker, which Marsh called late Pliocene. This, again, puts the date of the uplift not earlier than the end of the Pliocene.

THE ST. HELENA FAULT.

Northwest of Calistoga, on the western flank of Mt. St. Helena is an important fault. The shape of the mountain when viewed from the south suggests a fault block. The straight line of the top sloping gently to the eastward, and the precipitous descent to the west, have all the appearance of a tilted block with a fault escarpment. A trip on foot from the summit down the southwest side of the mountain, along the divide between Knight's Valley and the head of Napa Valley, demonstrated to the writer a condition of things as illustrated in Section AB. The throw of this fault must be at least 2,500 feet.

Age.—This fault probably took place at the time of the uplift which folded the Merced, since it appears to have been responsible for the high ridge of which St. Helena and Cobb Mountain are the culminating peaks, and to have preceded the great period

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*The Palaeontology and Stratigraphy of the Marine Pliocene and Pleistocene of San Pedro, Cal., Memoir Cal. Acad. of Sciences, Vol. III, p. 13.

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of erosion which resulted in the formation of Napa Valley, and the other large valleys, of a similar stage of topographical maturity, Sonoma and Santa Rosa. Napa Valley seems to have had its inception along the line of weakness due to the St. Helena fault. At Calistoga numerous hot springs occur. The writer does not know how far southward this fault extends. No evidence of it was found in Section CD.

SAN BRUNO FAULT.

At Bodega and Point Reyes Peninsula the pre-Franciscan granitics (diorite) have probably been brought to light by a great fault along the line of Bodega and Tomales Bay, seemingly the northwest extension of the San Bruno fault discussed by Lawson* in describing the geology of San Francisco Peninsula. Anderson suggests that this granite block during Tertiary times may have been independent in its oscillations from the mainland. Certainly Point Reyes Peninsula was beneath the waves during Monterey times, having been previously relieved by erosion of nearly all the pre-granitic sedimentaries and Franciscan which may have covered it, since Monterey shales are found resting on the worn surface of the granite. On the mainland, however, no Monterey is found nearer than the east shore of San Pablo Bay. The Monterey is greatly folded, occupying a synclinal basin in the granite, and the latter is consequently sheared and faulted.

Evidence of Faulting at Bodega Bay.—The only evidence of faulting the writer obtained at Bodega Bay was:

1. The direction and shape of the bay, apparently merely a northerly extension of the peculiarly long and narrow Tomales Bay.
2. The very general crushed and sheared appearance of the Bodega diorite, and numerous minor faults shown in it by the pegmatite dykes.
3. The entire absence of Franciscan on Bodega Peninsula, and of diorite on the east side of the bay.
4. The general westward trend of the Franciscan strata along the east shore, pointing across the bay more or less toward the diorite, as if abutting upon it.

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*U. S. G. S, 15th Ann. Rpt.

Age.—It seems likely that this fault is the northward extension of the San Bruno fault, which Lawson thinks was formed about the time of the tilting of the Merced.

GEOMORPHOLOGY.

From the summit of Mt. St. Helena a magnificent view is obtained of most of the area embraced in this paper. On clear days the Sierras may be seen in the hazy distance beyond the great Sacramento Valley, while to the west steamers may be sighted on the waters of the Pacific. To the North Cobb Mountain shuts off the view, but southward is the beautiful Napa Valley stretching away toward San Francisco Bay, with Mt. Diablo plainly discernible in the distance.

The Elevated Coastal Peneplain.—An interesting feature is the very even, almost horizontal crest line of many of these ridges. The one immediately adjacent to the coast appears to have a very uniform elevation in the neighborhood of 800 feet for many miles south of the Russian River. The break where the latter cuts through scarcely makes any visible impression on this coast line. The ridge is composed entirely of Franciscan strata, and has resisted erosion sufficiently to retain a suggestion of its old topographic form. It is evidently an old elevated and dissected peneplain.

Wide, Flat-bottomed Valleys of Erosion.—One of the most striking peculiarities of the topography is the succession of parallel ridges extending in a roughly northwest and southeast direction, and separated by wide, flat-bottomed valleys.

Synclinal Valleys and Subsequent Drainage.—Between this coastal ridge and Mt. St. Helena the hills are lower and not so even in crest-line, being composed of hard lavas alternating with soft tuffs and sandstones. This very fact has contributed to the rapid maturing of the topography, causing the streams to become largely subsequent in their nature, and to seek out the synclinal and widen them as they approached base level, into large, flat-bottomed valleys, such as Santa Rosa and Sonoma, with well defined terraces up to 350 feet above the present flood plain.

To the east is the wide, flat-bottomed Berryessa Valley, which is also of the nature of a subsequent valley. It is not located in a syncline, however, being along a contact between Knoxville shales and sandstones dipping to the northeast, and large masses of serpentine and Franciscan rocks.

The Tertiary volcanics once arched over this district, as shown by the sections, and the valley may have started in a syncline of Tertiary rocks which have now all been removed by erosion. Immediately east of this valley is a very high ridge, the crest of which is a very level sharp line about 2,600 feet above sea-level for many miles north and south. This ridge owes its even crest line to differential erosion, the alternation of hard sandstone and limestone with soft shale in the Knoxville series being peculiarly adapted to such weathering.

East of the above mentioned high ridge, but not visible from Mt. St. Helena, are the subsequent valleys of Capay and Pleasant. Here again the streams flow along a contact between comparatively hard rocks and later softer ones, the Tertiary gravels and soft sandstones overlying the Knoxville along this line.

Marine Terraces.—Anderson states that at Point Reyes Peninsula well defined wave-cut terraces occur up to 300 feet above sea-level. In the portion of the coast with which the writer is most familiar, namely, the vicinity of Bodega Bay, the only well defined shelf is lower than this. On the eastern side of the bay and northward toward the Russian River is a wide wave-cut shelf of an average width of about one-quarter of a mile and an elevation at its front edge of from twenty-five to thirty-five feet above sea-level. This slopes gently upward toward the hills, and at its back are frequently seen residual stacks and talus from the old sea-cliff. A thin veneer of gravel occurs in places up to eighty or a hundred feet above sea-level. On the west shore of Bodega Bay, as already mentioned under Pleistocene deposits, is a distinct shelf cut in the diorite just about at high-water mark. It is about 300 yards wide, and covered with gravel and sand to a depth of 113 feet. The difference in the height of this terrace on the two sides of the bay may perhaps be due to comparatively recent movement along the Tomales Fault.

No well defined terraces were observed at Bodega Bay above the ones described. But the crest-line of the coastal ridge for a considerable distance north and south is very nearly horizontal. and at an elevation of about 750 to 800 feet above sea-level. From a point on the upper road from Bodega Bay to the town of Bodega, where it passes over the summit, the writer found numerous pholas-borings in large Franciscan boulders which may be residual stacks. At another place, about midway on the road between Freestone and Occidental, and at nearly the same elevation, as determined roughly by aneroid, pholas-borings were also observed.

Fault Origin of Mt. St. Helena.—Mt. St. Helena owes its height mainly to a great fault, previously described, which has elevated it at least 2,500 feet higher than the corresponding flows of lava on the west side of Napa Valley. There is no evidence of its ever having been a volcano. No crater, or residual neck, or heterogeneity of materials is present. On the contrary, it is made up of even, well defined flows of lava, which frequently show evidence in columnar structure of having cooled as surface flows. Mt. Cobb appears to be simply another point on this high ridge, though the writer has no personal knowledge of it.

A nearly straight line through Cobb Mountain and St. Helena southward would follow the high ridge east of Napa Valley, crossing the bay near the Straits of Carquines, passing south through Mt. Diablo, and, if continued farther south, would pass through Mt. Hamilton. This line is evidently the axis of the Range. Napa Valley has been determined partly by the St. Helena Fault, and partly by its synclinal nature toward the south.

Recent Submergence.—The recent subsidence which has affected this region is well illustrated at the mouths of all of the streams flowing into the ocean and the bay. Russian River, Salmon Creek, the Esteros Americano and San Antonio, and Drake's Bay at their mouths are wide, fiord-like bodies of water with very precipitous shores, while the streams such as Petaluma Creek and Napa Creek are mere sloughs in their lower limits, meandering through broad, flat tule land bordered by steep hillsides. That they represent a submerged area is apparent to the casual glance. Certain evidence exists to show that the submergence is going on at the present time in the vicinity of San Francisco Bay. In recent excavations made at Shell Mound Park, between Berkeley and Oakland, it was found that the base of the shell beds are now four feet below the ordinary high-tide mark. Since it is evident that the mound is a "kitchen-midden," and therefore built on the land, this fact proves that there has been in very recent times a subsidence of at least four feet.

Geomorphic Cycle.—The topography of this section then may be placed at a somewhat advanced stage in the geomorphic cycle, and, since this cycle must have been inaugurated not earlier than the beginning of the Pleistocene, the observer is immediately impressed with the enormous amount of erosion which has taken place, and the vast space of time represented by this the most recent period of geological history.

HISTORICAL RESUME.

After the intrusion of the pre-Franciscan strata by the granitics, a great period of erosion occurred, as shown by the great unconformity existing between Franciscan and the older rocks.

Upon this old, well worn surface the Franciscan series was laid down, the variety of the sediments giving evidence of frequent oscillations during their deposition, while the sharp folding and faulting that has taken place, and the volcanic intrusions, attest the immense amount of movement subsequent to their deposition.

During Shasta-Chico times probably the whole of this area was deep under the sea and the Sierras were undergoing erosion, for lying unconformably upon the Franciscan, as well shown in many places outside of this field, and suggested by the heavy chert conglomerate of Capay Valley, is a vast accumulation of thin-bedded shales and sandstones in monotonous rhymical succession, indicating deep-water deposition under certain peculiar, and as yet unexplained, conditions. At the most conservative estimate the Shasta-Chico strata in this territory have a thickness of five miles, and they are probably considerably thicker than this. The writer has no palaeontological evidence as to whether or not they include the Chico. Certainly no heavy beds of conglomerate were observed between the two, as seen on Yulen Creek in Shasta County, and at Berkeley.

Very little Eocene strata were recognized in this field, although they may exist in the lower foothills along the west side of the Sacramento Valley beneath the late Tertiary sedimentaries. The greater part of the territory to the west was probably underoing erosion during this period.

The present almost entire absence of Monterey in this large field, when it is known to be developed so extensively farther south, does not necessarily mean that the Monterey sea was confined to Point Reyes Peninsula, but the occurrence of San Pablo strata so near by, resting upon a very uneven Franciscan surface free from Monterey, points to the region having been dry land during Monterey times.

In spite of the enormous length of this erosion interval, from Eocene to the end of the San Pablo, the Franciscan does not appear to have reached the stage of a peneplain, and it is not until the end of the Pliocene that we find it reduced to that form.

The San Pablo strata are nowhere in contact with the known Monterey, so that the relations between the two are not clear in this field, it being impossible to tell whether there was an elevation of the region during the time between their depositon and that of the Monterey, or whether continuous sedimentation went on.

The blue San Pablo sandstone (tuff) at Carneros Creek indicates that the andesitic detritus reached at least as far north as the southern portion of this area. The sandstones and gravels of supposed Orindan age in Petaluma Valley, containing lignite beds and horse-teeth, indicate that lakes existed here during late Miocene or early Pliocene times.

Between the supposed Orindan and the Mark West Andesite there is a glaring unconformity. Hence it is probable that between the Orindan and the Merced there was an erosion interval followed by a gradual subsidence of the land, the sea encroaching from the west toward the east on the area now roughly represented by Santa Rosa and Petaluma Valleys. Seemingly part of the San Pablo beds to the west remained under water during the elevation of those farther east, for along the Estero San Antonio and at Freestone they lie nearly horizontal and conform in dip with the Sonoma Tuff. Just prior to the Merced period extensive volcanic disturbances took place, probably having their center somewhere northeast of Santa Rosa Valley. Among the reasons for this belief as to the locality of the center of disturbance are the position of the overturned redwoods of the Petrified Forest, with their roots pointed to the northeast, and the great thickness of the tuffs and lava flows in their vicinity.

The volcanic disturbance was very great, and continued throughout the whole of the Merced. The first outflows consisted of pyroxene-andesite, which in the neighborhood of Mt. St. Helena aggregates a thickness of about 1,500 feet. Following this came a great outthrow of andesitic pumice and lapilli, with occasional thin flows of basalt, which spread over the country to a maximum depth of nearly 2,000 feet, and were carried down the streams into the lakes and seas, forming beds of tuff and conglomerate from ten to two hundred feet thick.

While the volcanoes were throwing out this vast amount of ashes and fragmental material, deposits, other than the tuff, were forming in the seas and lakes, particularly in the region to the west. Buff colored sandstone, and fine conglomerate with numerous volcanic pebbles similar to those of the tuff, were deposited in the region of Santa Rosa Valley to the depth of between 2,000 and 3,000 feet. In the upper part of these beds (Wilson Ranch Beds) fossils of Merced age were preserved. Lakes of great size probably existed, since the relation of the upper lava flows, the St. Helena Rhyolite, to Becker's Cache Lake Beds, and the correlation of the latter by Marsh with the late Pliocene, point to a large Merced lake in that neighborhood.

While the sediments were depositing in the seas and lakes, large rivers were forming deltas with coarse gravels to great depths, thus showing that a gradual subsidence was taking place. A good illustration of this may be seen between Mark West Springs and Santa Rosa Valley, where at least 2,000 feet of coarse gravel has accumulated. The history of this old delta bears a striking similarity to that of the Santa Clara-San Benito Valley.*

***The Post-Pliocene Diastrophism of the Coast of Southern California. Lawson. Bull. Dep. Geol., Univ. of Cal., Vol. 1, No. 4, p. 151.**

During the gradual subsidence thus indicated, the sea probably encroached on the land from the west at Santa Rosa Valley to form marine deposits.

So far as the writer's personal observation goes, the last flow of lava in this area was the St. Helena Rhyolite, which in the vicinity of Mt. St. Helena has a thickness of at least 2,000 feet. This flow seems to have occurred at the end of the Merced, since it everywhere overlies the Sonoma Tuff and the Cache Lake Beds, and no pebbles of it are found in the Wilson Ranch Beds. Since it is folded conformably with the Sonoma Tuff, and hence preceded the uplift and the great period of erosion which followed, it is probably not later than the very latest Merced. Becker[*] states that a later flow of basalt took place to the north, in the Clear Lake region.

The great uplift which raised and folded all the Merced strata is supposed by Lawson[†] to have taken place just at the beginning of the Pleistocene. More recent work by Arnold[‡] on the upper portion of the Merced, at Seven Mile Beach, points to its somewhat later age. The fact that the St. Helena Rhyolite, fully 2,000 feet thick in places, rests conformably upon the Merced sedimentaries, and is folded with them, would seem to suggest this view, if we could be sure that the Wilson Ranch Beds represent the whole of the Merced, but at present the palaeontological evidence is not strong enough to settle this point.

At Wilson's Ranch *arca trilineata* is very common, and Ashley states that these large areas are common toward the base of the Merced, but disappear before the top is reached. Hence the Wilson Ranch Beds may represent only the lower part of the Seven Mile Beach Beds.

Probaby during the time of this folding the St. Helena fault occurred, by which the strata were displaced nearly 3,000 feet, and the high ridge formed of which Mt. St. Helena and Cobb Mountain are the culminating points. Probably about the same time the San Bruno Fault on San Francisco Peninsula, and its northern extension, the Tomales Fault, occurred, although, as suggested by Anderson, there may have been oscillations along this line in early Tertiary times.

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[*] Mon. XIII, U. S. G. S., pp. 157 and 223.

[†] Post Pliocene Diastrophism of the Coast of Southern California. Bull. Dept. Geol., Univ. Cal., Vol. I, No. 4, p. 157.

[‡] Memoirs Acad. of Sciences, Vol. III, p. 13.

After the folding an uplift occurred which was not continuous, but was marked by periods of rest, and possibly of reversal of motion, since along the coast these stoppages are recorded by wide, wave-cut terraces. The coast line of this section is made up almost entirely of Franciscan rocks, which do not resist erosion well enough to preserve the terraces higher than about 300 feet, the elevation of those at Point Reyes. The coastal ridge between the writer's two sections has a very even crest-line at about 800 feet above sea-level, and on this he has found pholas-borings at two places. To the north, however, Lawson* states that a well defined wave-cut shelf exists at 1,520 feet, with many others at lower elevations.

While this gradual elevation was taking place the streams were dissecting and wearing down the rising land, and the immense amount of erosion which has taken place since the inauguration of the post-Pliocene uplift is a measure of the vast length of time represented by the Pleistocene. The geomorphic cycle which had its beginning in the post-Pliocene times has already reached a stage of early maturity.

Following this elevation, and possibly only one of the retrograde steps in the general elevation of the coast, came the most recent submergence of the region, as evidenced by the flooding of the lower valleys of the streams and the formation of fiord-like estuaries at Russian River, Drake's Bay, Estero Americano, and San Antonio, Tomales Bay, and the great San Francisco Bay itself, with its estuaries such as Petaluma Slough and Napa River.

Evidence exists in submerged "Kitchen-middens" to show that this submergence is still going on at a rate which may be measured in terms of inches and hundreds of years.

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*Geomorphogeny of the Coast of Northern California. Bull. Dept. Geol., Univ. of Cal., Vol. I, No. 5.

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ARCAS OF THE CALIFORNIA NEOCENE.

BY

VANCE C. OSMONT.

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INTRODUCTION.

Among the most characteristic fossils of the California Neocene the arcas have an important place. They are widely distributed, both horizontally and vertically, in the geological section. They seem to have been present in all parts of the region and at all depths in the water. The species, being generally short lived, are especially useful for age determinations. Unfortunately the species have not been well defined or figured, and some of the most characteristic ones have not been described. In the following paper the writer has presented a comparison of the described species, and a description of the forms recognized by him, together with memoranda of their occurrence and the associated fauna.

In this work the writer has had access to the collections of the University of California, Stanford University, the California Academy of Sciences, and the California State Mining Bureau.

ARCA MICRODONTA, Conrad.

Plate 8.

Arca microdonta. Conrad, 1853-4. Pac. R. R. Reps., Vol. V, p. 323, Pl. III, fig. 29.

Description.—This species was originally described by Conrad as follows: "Rhomboidal, ventricose, thick in substance. anterior side very short, umbonal slope rounded. Ribs 25, prominent, narrow, wider posteriorly except on posterior slope, where they are small, and not prominent, about five in number. Cardinal teeth small, numerous, closely arranged, margin profoundly dentate, dorsal area rather wide and marked with about six impressed lines, beaks distant."

The variations in this form, as shown in figs. 1*a* to 3*b*, is considerable, and was at first thought to be of specific value. The specimen shown in figs. 2, 2*a*, and 2*b* was, however, found to bridge over the differences and lie near Conrad's type. It was accordingly figured as the best representative of the type, along with outline representations of other forms in figs. 1*a*, 1*b*, 3*a*, and 3*b* for comparison. The specimen shown in figs. 3*a* and 3*b* is rather small, measuring 45x33 mm. It is more ventricose and more inequilateral than *A. trilineata*. It has 27 somewhat beveled ribs, showing no sign of a median groove. The shell is wide and heavy, with high beaks separated by a profound ligament area. The posterior end is noticeably concave as far forward as the fifth or sixth rib, as shown in Conrad's figure.

The individual represented in figs. 1*a* and 1*b* is very inequilateral, extremely ventricose, with beaks very heavy and high, and the ligament area flaring and enormously developed, making the thickness of the closed shell fully as great as its height. The hinge line is relatively short, the beaks strongly incurved, though very distant, and placed so close to the anterior end as to make this portion of the shell appear almost flat. The posterior end is pointed, and that portion near the hinge concave. The basal margin is nearly straight, and parallel to the hinge line. The ribs number 25 or 26, and are narrow and without grooves. The growth lines tend to produce a beaded effect.

The specimen displayed in figs. 2, *2a* and *2b* appears to bridge over the differences between those of figs. 1 and 3. It has 26 ribs.

Occurrence and Associated Fauna.—The specimen shown in figs. *3a* and *3b* is labelled Santa Monica. In the Geology of California Whitney states that the fossiliferous sandstones of Santa Monica have yielded the following fauna:

Nererita recluziana Desh.
Turritella ocoyana Conr.
Trochita costellata Conr.
Cerithidea sacrata Cpr.
Cardita subtenta Conr.
Mytilus edulis Linn.

Turritella ocoyana alone shows this horizon to be lower Miocene.

The specimen shown in figs. *1a* and *1b* was collected by Eldridge from a limestone series below the silicious shales of the Devil's Den region, in Kern County. Here were also found:

Astrodapsis tumidus Rém. or possibly *Clypeaster brewerianus* Rém.
Pecten pabloensis Conr.
Pecten sp., very large.
Ostrea sp.

The form shown in figs. 2, *2a* and *2b* is from an unknown locality.

A. microdonta seems to be a very variable, and is, so far as known, confined to the Miocene.

ARCA TRILINEATA Conrad.

Plate 9, Figs. 4—4c.

Arca trilineata Conrad. Pac. R. R. Reps., 1854-5, Vol. VI, p. 70, Pl. II, fig. 9.
Arca sulcicosta Gabb. Palaeontology Cal., Vol. II, p. 31, Pl. 9, fig. 53.
Arca schizotoma Dall. Trans. Wag. Fr. Inst., Vol. 3, Pt. 4, p. 659.

Description.—Conrad's description is as follows: "Trapezoidal, somewhat produced, inequilateral, ventricose, ribs 22-24, scarcely prominent, square, wider than the intervening spaces, ornamented with three impressed or four raised lines: disk concentrically wrinkled: summits prominent; beaks approximate. Length 3 inches."

Gabb gave the following description: "Shell thin, broad: beaks prominent, incurved, approximate, slightly twisted anteriorly; hinge line short; ends and base pretty regularly rounded, posterior basal portion a little the most prominent; area very narrow, slightly sunken. Surface marked by about 25 prominent square ribs, with flat, equal interspaces; these ribs are each marked by a more or less distinct median groove, and crossed by pretty strong concentric lines of growth, breaking up the surface into a beautiful beading. Hinge straight, composed of numerous fine teeth, very small and irregular in the middle, longer and slightly oblique toward the ends."

This shell is ordinarily elliptical to quadrate in form and inequilateral. The ratio of length to height is about 1¼ to 1. The size of average adults is about 77 x 63 mm. The beaks are prominent, close together, wide, centrally located, and strongly incurved over a ligament area which though wide is not flaring. The elevation of the ligament area and width of the beaks makes the upper margin appear strongly rounded.

There are 25-27 ribs. These are flattened, considerably wider than the interspaces and marked by a very distinct median groove, to which are added toward the margin in old individuals, two subsiduary grooves, and later in the largest specimens an additional pair. In these latter the ribs toward the margin are often several times as wide as the intervening spaces. Crossing the ribs are numerous closely arranged lines, giving the shell a beautiful beaded effect, especially well shown in younger individuals.

This species becomes very large, some individuals being observed 114 x 76 mm. The smaller individuals showing the heavily beaded ribs have generally been considered as Gabb's *A. sulcicosta*, the larger being referred to Conrad's *A. trilineata*. A number of fine specimens from Capitola, and also a good suite from Russian River, show the apparent specific differences to be merely those of age.

Occurrence and Associated Fauna.—Conrad gives Santa Barbara as the type locality for *A. trilineata*, and lists the following fauna from that place:

Mulinia densata Conr.
Arca trilineata Conr.
Arca canalis Conr.
Janira bella Conr.
Pandora bilirata Conr.
Cardita occidentalis Conr.
Diodora crucibuliformis Conr.

Gabb states that *A. sulcicosta* is found at Santa Barbara, Santa Rosa, Valley of Russian River, Half Moon Bay, Capitola, Foxins (Griswold's ?), San Fernando. He calls the above formation Pliocene and lists the following fauna:

SANTA BARBARA (Gabb).

Neptunea tabulata Baird.
Lunatia lewesii Gld.
Crepidula grandis Midd.
Schizothaerus nuttalli Conr.
Lutricola alta Cpr.
Macoma edulis Nuttl.
Caryatis barbarensis Gabb.
Tapes tenerrima Cpr.
Saxidomus gracilis Gld.
Cardita ventricosa Gld.

SANTA ROSA (Gabb).

Nassa fossata Gld.
Crepidula princeps Conr.
Modiola recta Conr.
Machaera patula Cpr.
Cryptomya californica Conr.
Macoma nasuta Conr.
Chione succinta Val.
Tapes staminea Conr.
Lucina borealis Linn.
Solen rosaceus Cpr.
Axinea patula Conr.
Arca sulcicosta Gabb.

SAN FERNANDO (Gabb).

Lucina richthofeni Gabb.
Lucini borealis Linn.
Neptunea tabulata Baird.
Neptunea humerosa Gabb.
Nassa fossata Gld.
Nassa perpenguis Hds.
Purpura saxicola Val.
Lunatia richthofeni.
Lunatia lewisii Gld.
Neverita recluziana Desh.
Sinum planicostum Gabb.
Conus californicus Hinds.
Cancellaria altispira Gabb.
Tritonium cooperi.
Crepidula grandis Midd.
Crepidula dorsata Brod.
Calliostoma costata Mark.
Acmaea rudis Gabb.
Bulla nebulosa Gld.
Solen rosaceus Cpr.
Siliqua edulata Gabb.

At Wilson's Ranch, Russian River, near Mark West Creek, the writer has collected the following:

Tapes staleyi Gabb.
Macoma nasuta Conr.
Standella sp.
Schizothaerus nuttalli Conr.
Natica clausa Brod. and Sby.
Natica lewisii Gld.
Olivella biplicata Sby.
Neptunea tabulata Baird.
Arca trilineata Conr.
Nassa perpenguis Hds.
Cardium corbis Martyn.
Crepidula grandis (?) Midd.
Purpura saxicola Val.
Solen sp.
Pleurotoma sp.

In Ashley's paper on the "Neocene of the Santa Cruz Mountains," he gives the following fauna for presumably the same beds as those Gabb refers to at San Fernando, though he mentions no arcas. He calls it Merced, transitional in the lower part:

Amusium caurinum Gld.
Cancellaria cf. *vetusta* Gabb.
Calyptraea filosa Gabb.
Cardium meekianum Gabb.
Chione simillima Sby.
Crepidula rogosa Nuttl.
Dentalium hexagonum Sby.
Dosinia ponderosa Gray.
Drillia torosa Carpt.
Lunatia lewesii Gld.
Macoma nasuta Conr.
Myurella simplex Carpt.
Nassa californiana Conr.
Ostrea veatchii Gabb.
Neptunea humerosa Gabb.
Pachypoma gibberosum Chem.
Liropecten estrellanus Conr.
Pisania fortis Carpt.
Saxidomus gibbosus Gabb.
Solen sicarius Gld.
Turritella cooperi Carpt.
Turritella jewetti Carpt.
Venericardia ventricosa Gld.

For the section from Montara to Capitola, Ashley gives a fauna of fifty-two species, which includes three arcas. There is little doubt that his *A. microdonta* is really *A. trilineata.* Since he states that "In these strata we find great numbers of several species of arca, some of which are over four inches broad." And after examining a large number of specimens from Capitola I find all these large arcas to be *A. trilineata.* The young individuals are identical with *A. sulcicosta.* Conrad described *A. canalis* from the same bed with *A. trilineata*, and the writer has seen specimens from Half Moon Bay. Ashley calls the main bulk of these beds Merced; the lower part, or pecten beds, where *Pecten caurinus* is very abundant, he calls transition beds, considering them to be in part Miocene.

MONTARA TO CAPITOLA. (Ashley).

Astyris gausapata Gld.
Calyptraea inornata Gabb.
Cancellaria tritonidea Gabb.
Chorus belcheri Hinds.
Crepidula grandis Midd.
Cryptichiton cf. *stelleri* Midd.
Lunatia lewisii Gld.
Nassa californiana Conr.
Nassa perpenguis Hds.
Natica clausa Brod. and Sby.
Chrysodomus humerosus Gabb.
Chrysodomus tabulatus Baird.
Purpura crispata Chem.
Purpura saxicola Val.
Surcula carpenteriana Gabb.
Volutilithes indurata Conr.
Acila castrensis Hinds.
Arca canalis Conr.
Arca microdonta Conr.
Arca sulcicosta Gabb.
Cardium corbis Martyn.
Cardium meekianum Gabb.
Chione simillima Sby.
Cryptomya californica Conr.
Cyrena californica Gabb.
Glycimeris generosa Gld.

Lucina borealis Linn.
Macoma nasuta Conr.
Macoma edulis Nuttl.
Meretrix traskii Conr.
Modiola flabellata Gld.
Mya truncata (?)
Pachydesma inezana Conr.
Pecten caurinus Gld.
Pecten pabloensis Conr.
Pecten propatulus Conr.
Psammnobia rubroradiata Conr.
Sanguinolaria nuttalliana Conr.
Saxidomus gibbosus Gabb.
Schizothoerus nuttalli Conr.
Siliqua patula Dixon.
Solen sicarius Gld.
Standella californica Conr.
Standella falcata Gld.
Standella nasuta Gld.
Tapes staminea Conr.
Tapes tenerrima Carpt.
Mectra pajaroensis Conr.
Yoldia cooperi Gabb.
Zirphoea crispata Linn.
Scutella gibbsi Rém.
Scutella interlineata Stimp.

The Wild Cat series of Lawson has yielded the following fauna, principally from the Scotia, Humboldt County, section:

Cardium meekianum Gabb.
Pecten caurinus Gld.
Tapes staleyi Gabb.
Schizothoerus nuttalli Conr.
Machaera patula Dixon.
Macoma edulis Nuttl.
Macoma expansa Carpt.
Macoma nasuta Conr.
Solen rosaceus Carpt.
Standella falcata Gld.
Thracia trapezoides Conr.
Modiola multiradiata Gabb.
Mytilus californianus Conr.
Saxidomus gibbosus Gabb.
Yoldia impressa Conr.
Balanus sp.
Neptunea altispira Gabb.
Neptuna tabulata Baird.
Drillia voyi Gabb.
Olivella boetica Carpt.
Lunatia pallida Brod. and Sby.
Purpura canaliculata Ducl.
Columbella richthofeni Gabb.
Scutella interlineata Stimp.
Cancer breweri (?) Gabb.
Nassa fossata Gld.
Cardium blandum Gld.
Psephis lordi (?) Baird.
Standella planulata Conr.
Natica clausa Brod. and Sby.
Fusus, n. sp.
Mactra sp.
Arca sulcicosta Gabb.
Priscofusus oregonensis Conr.
Priscofusus devinctus Conr.
Priene oregonensis Redf.

This formation has been correlated with the Merced of Seven Mile Beach.

Mr. F. M. Anderson of the California Academy of Science kindly showed the writer specimens of this species from the San Pablo, associated with the following fauna:

KETTLEMAN HILLS, FRESNO COUNTY, CALIFORNIA.

Pseudocardium gabbi Rém.
Cardium meekianum Gabb.
Scutella gibbsi Rém.
Ostrea bourgeoisi Rém.
Balanus sp.
Pecten sp.

ZAPATO CHINO CREEK, FRESNO COUNTY, CALIFORNIA.

Saxidomus aratus Gld.
Clypeaster (Scutella) brewerianus Rém.
Astrodapsis tumidus Rém.
Scutella gibbsi Rém.
Neverita recluziana Petit.
Nassa californiana Conr.
Pecten sp.

TAR RANCH.

Chione sp.
Scutella gibbsi Rém.
Tapes staminea Conr.
Neverita recluziana Petit.
Zirphaea dentata Gabb.

Arca trilineata appears first in the San Pablo, though how far down in this formation is not yet certain, and extends through the lower and middle Merced, disappearing somewhere between the Middle Merced and the Upper Gastropod Bed of the Seven Mile Beach section. It is most abundant in the Lower and Middle Merced.

ARCA MONTEREYANA, new species.

Plate 9, Figs. 5, 5*a* and 5*b*.

Description.—Rhomboidal, inequilateral, nearly two-thirds of the length being behind the beak, posterior margin making a very obtuse angle with hinge-line. Ratio of length to height about 1½ to 1. Average size of adult about 51 x 33 mm. Beaks not prominent, turned rather sharply forward, narrow and close together, ligament area narrow. Hinge line long and straight. Basal margin nearly parallel to hinge line. Ribs 26-32, usually 27, prominent, square, flattened, a little wider than the interspaces and marked with a median groove. Occasionally, in the older specimens, two subsidiary grooves may appear toward the margin, as in *A trilineata*. More or less distinct lines of growth often roughen the shell, especially in the larger individuals, and when these are fine and numerous they approach closely the beaded effect of *A. trilineata*.

This shell is distinguished from *A. trilineata* and *A. canalis* by its more inequilateral form, low, narrow beak, greater proportional length, long straight hinge-line and generally less inflated shell. The latter characteristic, together with the median grooves on the ribs, distinguishes it from *A. microdonta*.

Occurrence and Associated Fauna.—This species occurs most abundantly in the sandy phases of the Monterey Miocene associated with the shale, and sometimes in the shale itself. In the latter case it is usually small. It rarely occurs in the typical shale. At Selbys, near Vallejo Junction, it is found in a calcareous layer in the shale with the same fauna as that in the sandy layers below.

It is common in the Monterey of the Pinole section. It is also found at Walnut Creek. It probably occurs in the typical shale at Carmelo Bay, and is also found at Barker's Ranch, near Bakersfield. It is most abundant in the middle Monterey, where it is associated with the following fauna:

Crepidula grandis Midd.
Glycimeris generosa Gld.
Pandora scapha Gabb.
Yoldia cooperi Gabb.
Leda taphria Dall.
Solen sp.
Lunatia lewesii Gld.
Tellina bodegensis Hinds.
Nassa, n. sp.
Siliqua patula Conr.
Lucina borealis Linn.
Chione succincta Val.
Callista, n. sp.
Mactra sp.

At Barker's Ranch it is found with a fauna of lower Monterey age, as follows:

Agasoma barkerianum Cpr.
Agasoma kernanum Cpr.
Agasoma, n. sp.
Turritella ocoyana Conr.
Conus, n. sp. near *californicus* Hds.
Surcula carpenteriana Gabb.
Pleurotoma sp.
Trochita sp. like *filosa* Gabb.
Myurella sp. like *simplex* Carpt.
Cancellaria sp (a) new.
Cancellaria sp. (b) new.
Dosinia sp.
Nassa sp. near *perpenguis* Hds.
Nassa sp.
Neptunea, n. sp.
Leda taphria Dall.
Yoldia cooperi Gabb.
Lucina richthofeni Gabb.
Neverita recluziana Conr.
Natica ocoyana Conr.
Voluta, n. sp.
Standella indet.
Crucibulum sp.
Dentalium sp.
Solen sp.
Pecten sp.
Tellina sp.

The writer has seen specimens of this species collected by Anderson and associated with the following lower San Pablo fauna:

Pecten pabloensis Gabb.
Pecten estrellanus Conr.
Dosinia ponderosa Gabb.
Lucina borealis Linn.
Tapes tenerrima Gabb.
Mytilus californianus Gabb.
Mactra (Spisula) falcata Gld.
Macoma inquinata Desh.
Mactra (Pseudocardium) sp.
Hemifusus sp.
Trophon (aff. T. ponderosum) Gabb.
Neverita recluziana Desh.
Trochita sp.
Astrodapsis tumidus Rém.
Sharks' teeth.

This seems to be a characteristic Monterey Miocene species. most abundant in the middle portion of that formation, but also found in the lower and upper part, and in the lowermost San Pablo.

ARCA CAMULOENSIS, new species.

Plate 10, Figs. 6 and *6a*; Pl. 11, Figs. *6b* and *6c*.

Description.—Shell quadrate to circular, height only slightly less than length, (adult 90 x 98 mm.), almost equilateral, thickness through closed shell nearly equal to height. Beaks not widely separated, very slightly turned forward, and greatly incurved over a wide and flaring ligament area. Ribs about 32 in number, rounded and without grooves, considerably wider than the interspaces, and crossed by regular ridges, which give them a beaded structure. At about the ninth rib from the posterior end is a very distinct shoulder, from which there is a steep concave slope to the posterior margin.

Occurrence and Associated Fauna.—*A. camuloensis* occurs near Camulos, Ventura County, in the Puente Hills, Los Angeles County, and in the foothills of the Santa Ana Mountains.

Associated fauna five miles northeast of Camulos:

Cancellaria, n. sp.
Cardium, indet.
Chrysodomus, n. sp.
Conus californicus Hds.
Nassa californiana Conr.
Natica, sp. indet.
Pachypoma, n. sp.
Turritella, n. sp.
Acila castrensis Hds.
Clementia subdiaphana Carpt.
Fusus ambustus Gld.
Lutricola alta Conr.
Natica (Lunatia) lewisii Gld.
Nucula, n. sp.
Ostrea veatchii Gabb.
Pecten cerrosensis Gabb.
Priene oregonensis Redf. sp.

It is reported from the Puente Hills* associated with a fauna determined as of Pliocene age. This form is not distantly removed from *A. grandis*, but can be distinguished from it by both the form of the shell and the character of the ornamentation.

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*Bull. No. 19, Calif. State Mining Bureau, pp. 220-222.

ARCA CANALIS Conrad.

Plate 11, Figs. 7, 7a and 7b.

Arca Canalis Conrad. Pac. R. R. Reps., 1854-5, Vol. 6, p. 70, Pl. 2, fig. 8.

Description.—This species was described by Conrad as follows: "Subtrapezoidal, ventricose, ribs 24-26, flattened, scarcely prominent, divided by a longitudinal furrow, disk concentrically wrinkled, umbo ventricose, summits prominent, remote from the center."

There seems to be little difference between this form and *A. trilineata,* the principal difference being that the beaks are more distant and less incurved and the ligament area in *A. canalis* more flaring. The additional grooves, and also the beaded effect of *A. trilineata,* seem to appear occasionally on *A. canalis* also. The flare of the ligament area does not appear to be an absolutely constant factor, and its importance as a specific character is somewhat doubtful.

Occurrence and Associated Fauna.—This species occurs at Santa Barbara, as noted by Conrad, and is called Pliocene by him. Specimens are also known from the McKittrick Oil District, from a horizon very doubtfully referred to the San Pablo. It is cited by Ashley as occurring in the Half Moon Bay and the Capitola sections. The writer has seen specimens from Half Moon Bay. It seems therefore to be a form closely related to, if not identical with, *A. trilineata* Conr., and to have the same range as that species. It also occurs in the San Pablo of Zapato Chino Creek, Fresno County, the fauna of which is listed under *A. trilineata.*

CONCLUSIONS.

The above species comprise all the Neocene arcas of California, so far as the writer has been able to determine. Other species are mentioned by Conrad, viz.: *A. congesta* and *A. obispoana.* The figure of the latter is very poor. It may represent *A. montereyana,* but is not perfect enough for identification More investigation may, however, show it to be a valid species. The former might be the young of any one of several species.

As to vertical range, we may, from our present knowledge, fairly assume that:

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Arca microdonta belongs to the Monterey Miocene.

A. montereyana ranges from the lower Monterey Miocene through the middle and upper divisions, and into the lower San Pablo. It is very much more abundant in the middle Monterey than elsewhere.

A. canalis seems to extend from the middle San Pablo to the middle Merced.

A. trilineata is known in the San Pablo, though not certainly in the lowest member, and seems to extend to a point somewhat above the middle Merced. It is most abundant in the lower and middle *Merced.*

A. camuloensis is so far known from only a few localities, occurring in strata probably referable to the Pliocene.

Berkeley, California.
November 30, 1904.

EXPLANATION OF PLATE 8.

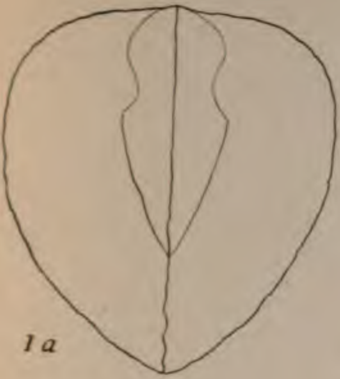
Arca microdonta Conr.

Figures natural size.

Figs. 1*a*, 2*a* and 3*a*.—Outline views of three individuals, seen from above.

Figs. 2 and 2*b*.—Lateral and anterior view of specimen, also shown in outline in fig. 2*a*.

Figs. 1*b*, 2*b* and 3*b*.—Outline views of three individuals, seen from anterior side. The individuals are the same as those shown in figs. 1*a*, 2*a* and 3*a*, and are arranged in the same order.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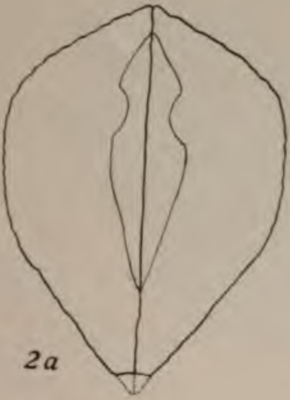
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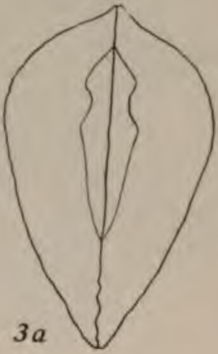
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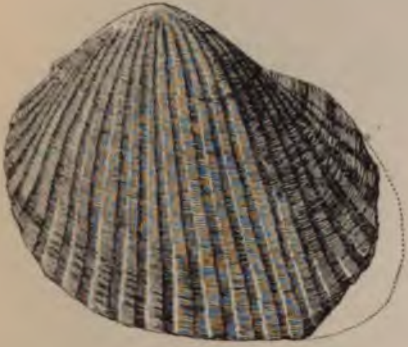
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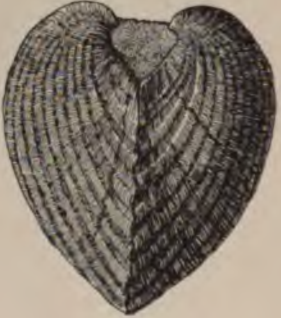
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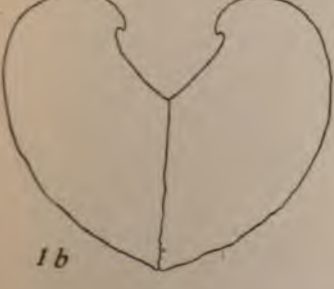
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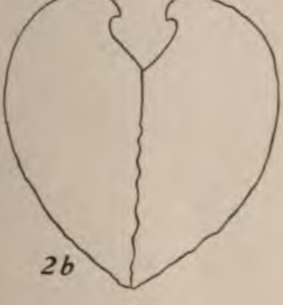
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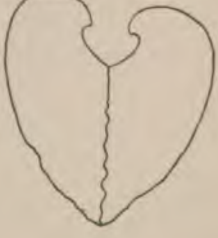
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EXPLANATION OF PLATE 9.

Fig. 4.—*Arca trilineata* Conr. Lateral view. Natural size.

Fig. 4a.—*Arca trilineata* Conr. Anterior view. Natural size.

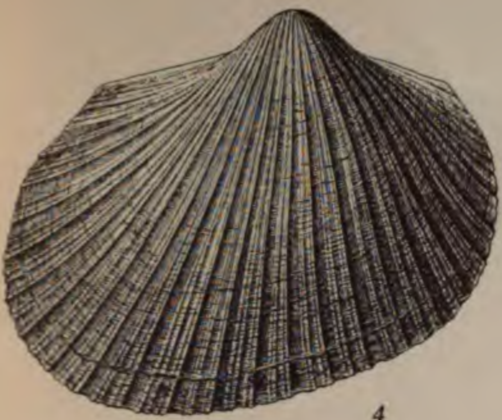
Fig. 4b.—*Arca trilineata* Conr. Hinge. Natural size.

Fig. 4c.—*Arca trilineata* Conr. Detail of beading on the ribs. ×2.

Fig. 5.—*Arca montereyana*, n. sp. Lateral view. Natural size.

Fig. 5a.—*Arca montereyana*, n. sp. Hinge and inner side of left valve. Natural size.

Fig. 5b. *Arca montereyana*, n. sp. Lateral view of valve shown in fig. 5a. Natural size.



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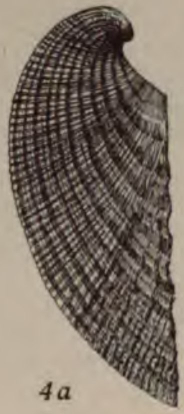

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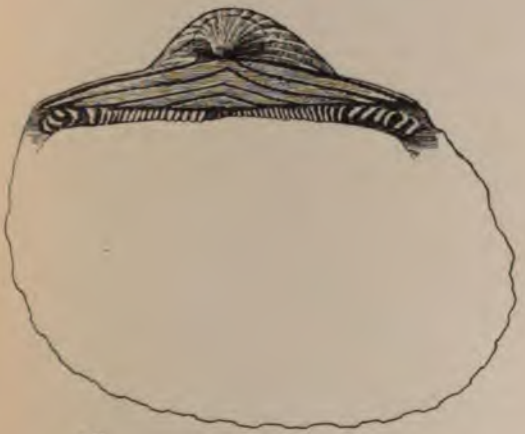

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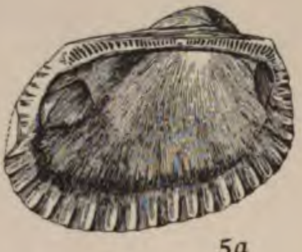

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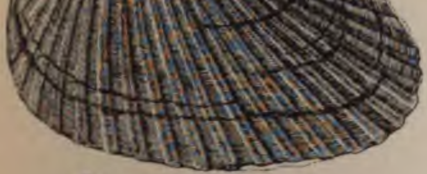

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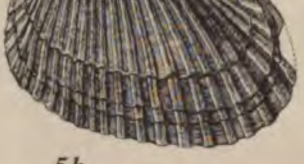

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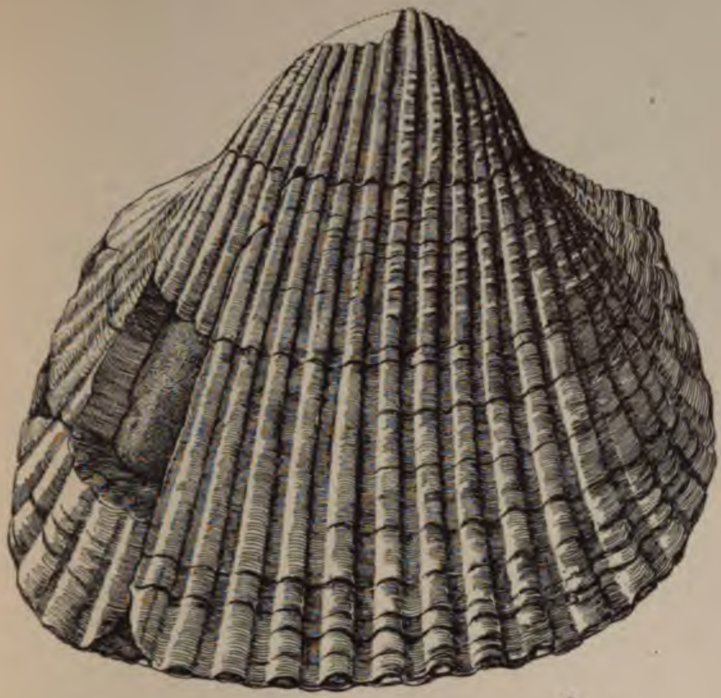
EXPLANATION OF PLATE 10.

Arca Camuloensis, n. sp.

Figures natural size.

Fig. 6.—Side view of a somewhat weathered specimen from which the surface sculpture has largely disappeared.

Fig. 6*a*.—Anterior view of specimen shown in fig. 6.



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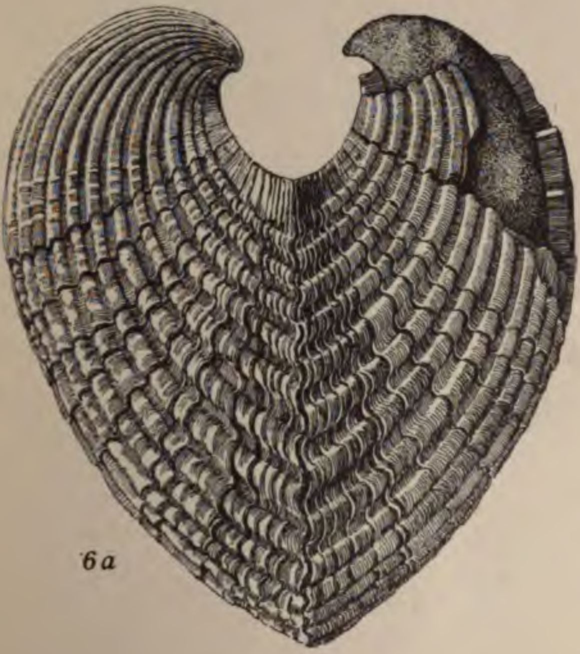

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EXPLANATION OF PLATE 11.

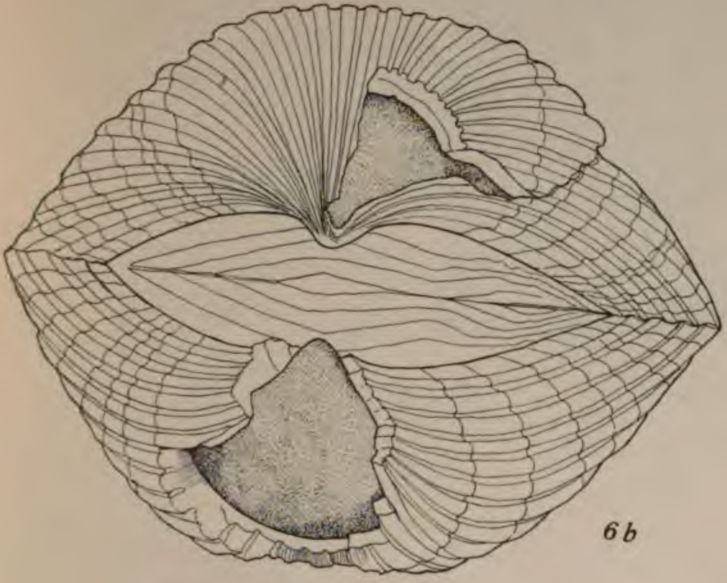
Fig. 6*b*.—*Arca camuloensis*, n. sp. Outline view of upper side of specimen shown on Plate 10. Natural size.

Fig. 6*c*.—*Arca camuloensis*, n. sp. Detail of rib ornamentation. ×2.

Fig. 7.—*Arca canalis* Conr. Side view. Natural size.

Fig 7*a*.—*Arca canalis* Conr. End view of specimen shown in fig. 7. Natural size.

Fig. 7*b*.—*Arca canalis* Conr. Hinge. Natural size.



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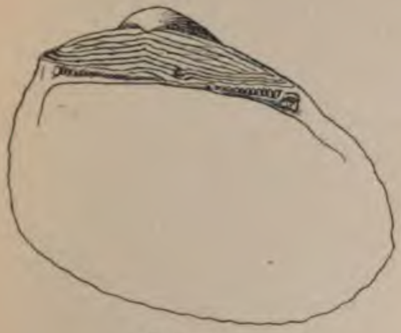

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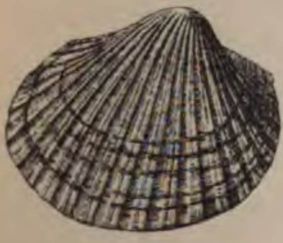

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CONTRIBUTION TO THE PALAEONTOLOGY OF THE MARTINEZ GROUP.

BY

CHARLES E. WEAVER.

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INTRODUCTION.

In the following paper an attempt has been made to bring together the already ascertained facts concerning the Palaeontology of the Martinez Group, and to add to them a considerable body of new evidence. The present investigation was begun by Professor J. C. Merriam, who made an extensive collection of Chico, Martinez and Tejon fossils from several localities in Contra Costa County, to the south and west of the town of Martinez. These formations were mapped by Professor Merriam in detail, the stratigraphic relationships were determined, and many new elements were recognized in the faunas. The completion of this work was suggested to the writer by Professor Merriam. The continuation of the investigation has consisted in an examination of all the known Martinez outcrops in the State, in the collection of additional fossils, in the study of the fauna with special consideration of correlation, and in the description of a number of new and characteristic forms.

During the early months of 1904, about four weeks of field work were devoted to a study of the geologic and stratigraphic relations of these formations in the vicinity of Benicia, Army Point and Martinez. Later in the year two trips were made to Lake County, where fossils of Martinez age were reported to occur. During the summer of 1904 about nine weeks were spent in mapping the Napa quadrangle, upon which are located the regions about Martinez and Benicia. In connection with this work an attempt was made to discover any stratigraphic relationships which might exist between the Martinez beds of Lake County and those in the vicinity of Karquines Strait. The study of the fauna has resulted in the description of twenty-one new species.

HISTORICAL REVIEW.

The Martinez formation was first recognized in 1869 by William M. Gabb* in volume two of his work on the Palaeontology of California. In the earlier volume† on the Palaeontology of California Gabb divided his Cretaceous into an upper and lower division, designating them as *A.* and *B* and including in the former all the beds now known as Chico, Horsetown and Knoxville. His upper division, Cretaceous *B*, comprised the upper division of the Eocene as known to-day. Later, in 1869, when the second volume of the Palaeontology appeared, this classification was more clearly defined. Cretaceous *A* was subdivided into the Shasta and Chico groups, and division *B* was named Tejon. Between the Chico and Tejon he provisionally placed the Martinez Group, which he considered to be of small geographical extent, and suggested that it might be a subdivision of the Chico.

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*Rep. Geol. Surv. of Calif. Palaeontology, Vol. II, p. 13 op. preface.

†Rep. Geol. Surv. of Calif. Palaeontology, Vol. I, 1864.

The list of fossils collected from the Martinez beds by Gabb appeared to indicate a possible transition from the Chico to Tejon, and when later the Tejon came to be regarded as Eocene, still more significance was attached to these "Intermediate beds."

The classification as set forth in the Palaeontology of the California Survey conflicted with later views, and hence led to confusion. This confusion was largely cleared up in a paper on the "Cretaceous and Eocene of the Pacific Coast" by Dr. T. W. Stanton,* in which he reorganized the earlier classification, basing it upon the results of more detailed investigations. In this new arrangement he divided the Martinez Group of Gabb into two parts and, on the basis of its faunal and stratigraphic relations, placed one part in the Chico and the other in the Eocene, designating the latter as lower Tejon.

In the following year a discussion of the question was published by Professor J. C. Merriam.† This investigation was based on a study of the geological relations of the Martinez Group at the typical locality. An extensive collection of fossils was made, extending into both the Chico below and the Tejon above. From the data obtained he was able to show that the Martinez fauna, consisting of over sixty species, was a unit quite distinct from the Chico and Tejon. Only a very few species were found in common with them. On a lithological basis he distinguished the Martinez from the adjoining formations, in that it showed the presence of considerable quantities of glauconite and possessed a peculiar gray color, in contrast with the yellowish or bluish rocks of the Chico and the more massive white to dull red Tejon sandstones. The thickness of the Martinez was estimated to be somewhere between one and two thousand feet. The results arrived at by Professor Merriam agree with those of Dr. Stanton, and the position of the Martinez beds was determined as in the lower Eocene. The Martinez was, however, recognized as a geological formation distinct from the Tejon.

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*The Faunal Relations of the Eocene and Upper Cretaceous on the Pacific Coast. 17th Ann. Rep. U. S. Geol. Surv., pp. 1011-1060, 1895-96.

†The Geologic Relations of the Martinez Group of California at the Typical Locality. Jour. of Geol., Vol. 5, pp. 767-775, 1897.

Dr. W. H. Dall,* in an article entitled "A Table of the North American Tertiary Horizons, Correlated with One Another and with those of Western Europe," correlates the Martinez and Tejon with the Midwayan stage of the southeastern United States and with the Cernaysian of Europe. In other words, he considers it to represent the extreme lower portion of the Eocene.

In an article written by Professor Andrew C. Lawson† in 1902 on "A Geological Section of the Middle Coast Ranges of California," the Martinez and Tejon are jointly termed the Karquines series. The combined thickness of the two is placed at 4,300 feet.

GEOGRAPHIC DISTRIBUTION.

The Martinez formation as at present known does not have an extensive geographic range. The best studied locality, and the one from which the formation takes it name, occurs in Contra Costa County, to the south and west of the town of Martinez. These beds run south from Martinez and disappear under the alluvium of Walnut Creek valley. A portion of it extends up Del Hambre Cañon to the northwest. To the east of Martinez and south of Bull's Head Point, another outcrop occurs, having a general northwest-southeast trend. On the opposite side of Karquines Strait, at the Benicia arsenal grounds, a continuation of these beds appears. They may be traced for a distance of three miles to the north of Benicia. Farther north, in southern Lake County, this same formation is again found. It first outcrops just east of the town of Lower Lake, and may be traced to the southeast for several miles. No connection of these beds with those farther south could be found, and from the structural relations between the two localities it does not seem probable that it ever existed. At the present time these are the only localities where beds of distinct Martinez age are recognized.

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*18th Ann. Rept. U. S. Geol. Surv., Pt. II, 1898, pp. 327-348.

†Science, N. S., Vol. 15, p. 416, 1902.

STRATIGRAPHIC RELATIONS.

The stratigraphic relations existing between the Martinez and either the Chico below or the Tejon above throw little light upon its separation as a distinct formation. As yet no contact has been observed where the exact relations between them can satisfactorily be determined, and at no locality in this region has a distinct angular unconformity been noticed.

In the vicinity of the Strait of Karquines the Chico, Martinez, Tejon and Monterey have all participated in the folding of the strata, which has resulted in the formation of a synclinal trough the axis of which has a northwest to southeast trend. The apex is situated about four miles to the north of Benicia. The maximum width of this syncline, extending from a short distance west of Pacheco on the east to Del Hambre Cañon on the west, is about four miles. In this cross-section the Chico, Martinez, Tejon and Monterey are found in succession toward the center of the syncline. The same holds true on the northern side of the straits, except that the Monterey is not represented.

To the south and west of Martinez, on the western limb of the syncline, all of these beds dip at high angles to the northeast. West of the syncline the Martinez becomes thinner, and is represented by a narrow strip extending up nearly to the head of Del Hambre Cañon. At this locality the Martinez, together with the Chico, dip to the southwest.

On the eastern flank of the syncline, beds of Martinez age are represented immediately west of Bull's Head Point, and south of this point they appear east of the road leading from Pacheco to Martinez. These, together with the Chico and Tejon, dip steeply to the southwest. The strike of these beds carries them across the Strait of Karquines, where they again outcrop just north of Army Point Station. At this point the formation was so thickly bedded that it was difficult to obtain accurate observations of the dip. Apparently, however, they dip at high angles to the southwest. In this locality the outcrops are separated from both Chico and Tejon by low marshes, so that no actual contact could be observed. However, no marked irregularity in the dip was seen. The strike of these beds was traced to a point about three miles northwest of Benicia. Farther than this no outcrops were seen which could definitely be called Martinez. To the west of Benicia thick bedded sandstones closely resembling those at Army Point were observed dipping steeply to the northeast. Farther west the Chico again occurs, dipping at the same angle as the thick bedded sandstones, but near the shore it is folded and again dips to the southwest. The strike and dip of these beds where carried across the straits are almost identical with those south and west of Martinez. The most reasonable conclusion would seem to be that there exists here a closely folded syncline.

Farther north, in Lake County, a similar structure seems to exist, viz: a closely folded syncline having a general northwest-southeast strike, with its apex about three miles northwest of the town of Lower Lake. The width of the syncline below Lower Lake is about three miles. The strata on both flanks dip at extremely high angles toward the axis. The formations represented are Chico, Martinez and Tejon. The areal extent of the Martinez outcrops was not determined, but they appear to be considerably greater than those about the Strait of Karquines. Beds of Martinez age may possibly be represented in northern Lake County, near the town of Upper Lake. Dr. H. W. Fairbanks,* who has examined that region, states that "a ridge of soft sandstone begins a mile northwest of Upper Lake and extends northwesterly for about ten miles between Middle Creek and Bachelor Valley. It rises perhaps one thousand feet above Clear Lake. The strata are thick bedded and almost level, and are underlain by the argillites of the older series which replace the sandstone on the northwest. It contains no fossils, but from its resemblance to the fossiliferous Chico-Tejon sandstones near Lower Lake, it is judged to be of that period." When more detailed field mapping is carried out the Lake County beds will probably be found to extend much farther to the southwest.

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*Geology of Tehama, Colusa, Lake and Napa Counties, Cal. State Min. Bureau, 11th Ann. Rept., p. 62, 1891-92.

The average thickness of the Martinez formation is about two thousand feet. On the north side of the straits it is much less. The section representing Martinez beds at Army Point railroad station has a thickness of about eighteen hundred feet. The Tejon above is nearly twelve hundred feet in thickness. In southern Lake County the Eocene is much thicker than at Martinez. The Martinez appears to be represented by at least twenty-five hundred feet of strata, and the Tejon by a volume nearly as great.

The Martinez beds are for the most part composed of thick bedded sandstones containing large quantities of glauconite, and alternating with these are considerable beds of shale. The shales are, however, not often seen, as they break down and do not show on the surface. In general the sandstones prevail. They vary somewhat in texture, and are sometimes cross-bedded. They generally have a grayish color, in contrast to the red Tejon. They are soft and break down easily. The variations in character are such as to distinguish upper and lower sections of the formation.

In the section at Army Point the lower two-thirds of the series is composed entirely of soft, thick bedded, light colored sandstones, while the upper third is made up of alternating beds of sandstone, varying in thickness from a few inches to several feet. They are more compact and more resistant to erosion than the lower portion of the series. The upper third of this series is fossiliferous. In the region about Lower Lake the same conditions prevail, except that the lower portion of the series is not entirely composed of thick bedded sandstones, but contains alternating layers of conglomerate, sandstone and shale, with a few beds of clay. Glauconite is very abundant. The fact that the deposits are so largely glauconitic is evidence that they were slowly deposited, and that the depth at which sedimentation took place was moderate.

Although there is no angular unconformity between the Chico and Martinez or the Martinez and Tejon, yet there exists a well marked faunal distinction. The fauna occurring in the Martinez beds is distinct, both from that above and below. Only four species range down into the Chico, and seven into the Tejon above, and these are in most cases species having an unusually long geological range. Altogether sixty-one species are entirely confined to the Martinez. In the hills south of Martinez a section was made across the western limb of the syncline. At various localities along this section collections of fossils were made from the Chico, Martinez and Tejon. In the lower beds a typical Chico fauna was represented, while above that several successive collections yielded an entirely distinct group of species. The upper portion of the series represents a fauna which is clearly Tejon.

The several successive collections made across the strike of the Martinez show a distinction between the faunas of the upper and lower portions. The following lists represent those forms occurring in the upper and lower portions in the vicinity of Martinez.

LOWER MARTINEZ.

Foraminifera, indet.
Fabellum remondianum Gabb.
Trochocyanthus zitteli Vaughn.
Schizaster lecontei Merriam.
Arca biloba, n. sp.
Cardium cooperi Gabb.
Cucullaea mathewsoni Gabb.
Leda gabbi Conrad.
Lima multiradiata Gabb.
Meretrix, sp.
Modiola merriami, n. sp.
Nucula truncata Gabb.
Pholadomya nasuta Gabb.
Tapes (aff.) *quadrata* Gabb.
Tellina martinezensis, n. sp.
Actaeon lawsoni, n. sp.
Cylichna costata Gabb.
Dentalium cooperi Gabb.
Discohelix californicus, n. sp.
Fusus aequilateralis, n. sp.
Neptunea mucronata Gabb.
Perissolax tricarnatus, n. sp.
Siphonalia lineata Stanton.
Urosyca caudata Gabb.
Urosyca robusta, n. sp.
Xenophora zitteli, n. sp.
Teredo, sp.
Turbinella crassatesta Gabb.

UPPER MARTINEZ.

Foraminifera nummuloid.
Schizaster lecontei Merriam.
Cancer, sp.
Arca biloba, n. sp.
Cardita hornii Gabb.
Cardium cooperi Gabb.
Cucullaea mathewsoni Gabb.
Leda gabbi Conrad.
Modiola merriami, n. sp.
Modiola ornata Gabb.
Nucula truncata Gabb.
Pholadomya nasuta Gabb.
Solen stantoni, n. sp.
Tellina martinezensis, n. sp.
Tellina hornii Gabb.
Tellina undulifera Gabb.
Thracia karquinesensis, n. sp.
Ampullina (conf.) *striata* Gabb.
Brachysphingus liratus Gabb.
Bullinula subglobosa, n. sp.

Dentalium cooperi Gabb.
Dentalium stramineum Gabb.
Ficopsis angulatus, n. sp.
Heteroterma gabbi Stanton.
Heteroterma trochoidea Gabb.
Heteroterma, indet.
Megistostoma striata Gabb.
Morio tuberculatus Gabb.
Natica, sp.
Perissolax tricarnatus, n. sp.
Perissolax blakei Gabb.
Siphonalia lineata Stanton.
Architectonica tuberculata, n. sp.
Strepsidura pacheoensis Stanton.
Tritonium impressum, n. sp.
Tritonium cocenicum, n. sp.
Tritonium pulchrum, n. sp.
Turritella infragranulata Gabb.
Turritella pachecoensis Stanton.
Turritella conica, n. sp.
Turris, sp. indet.
Urosyca caudata Gabb.

In the outcroppings just north of Army Point railroad station numerous fossils were obtained. A list of the known species from this locality is given in the table below.

These species are nearly all fairly abundant at this locality, and the majority of them occur in both the lower and upper portions of the series in the vicinity of Martinez. Since only the upper portion of the series is fossiliferous, the locality just north of Army Point station may be correlated with the Middle Martinez beds in Contra Costa County.

In southern Lake County fossils have been found at several localities on Herndon Creek, about one mile southeast of the town of Lower Lake. At a point about one-fourth of a mile southeast of the town, on the road to Knoxville, a large number of species have been found. Many of these are not represented in the vicinity of the Strait of Karquines. The lower five hundred feet of strata are non-fossiliferous, and resemble very closely the non-fossiliferous beds at Army Point. The majority of the fossils were collected about six hundred feet from the base of the series. The larger proportion of forms resemble those belonging to the upper beds at Martinez and not occurring in the lower. From the stratigraphic position of the beds and the nature of the included faunas it seems best to correlate the Martinez beds at both Benicia and Lake County with the middle and upper at Martinez.

The following table represents all the forms occurring in the Martinez group at Martinez, Benicia and southern Lake County. The occurrence of these species in the type section at Martinez, whether lower or upper beds, or both, is also indicated.

		Lower beds at Martinez.	Upper beds at Martinez.	Benicia.	Lake County.
1	Foraminifera nummuloid	..	×	..	..
2	Foraminifera, 3 sp. indet.	×	..	..	..
3	*Flabellum remondianum* Gabb	×	..	×	×
4	*Trochocyanthus zitteli* Vaughn	×	..	..	..
5	*Schizaster lecontei* Merriam	×	×	..	..
6	*Terebratullina tejonensis* Stanton	..	..	×	×
7	*Arca biloba*, n. sp.	×	×	..	..
8	*Cardita hornii* Gabb	..	×	..	..
9	*Cardium cooperi* Gabb	×	×	..	..
10	*Crassatella unioides* Stanton	..	..	..	×
11	*Cucullaea mathewsoni* Gabb	×	×	×	×
12	*Leda alaeformis* Gabb	..	..	×	×
13	*Leda gabbi* Conrad	×	×	..	×
14	*Lima multiradiata* Gabb	..	..	..	×
15	*Lucina turneri* Stanton	..	..	..	×
16	*Meretrix*, sp.	×	..	×	..
17	*Modiola merriami*, n. sp.	×	×	..	..
18	*Modiola ornata* Gabb	..	×	..	×
19	*Nucula truncata* Gabb	×	×	×	..
20	*Pholadomya nasuta* Gabb	×	×	×	..
21	*Pectunculus veatchi, var. major.* Stanton	..	..	..	×
22	*Plicatula ostreiformis* Stanton	..	..	..	×
23	*Solen stantoni*, n. sp.	..	×	..	..
24	*Tapes* (aff.) *quadrata* Gabb	×	..	×	..
25	*Tellina martinezensis*, n. sp.	×	×	..	..
26	*Tellina hornii* Gabb	..	×	..	×
27	*Tellina undulifera* Gabb	..	×	×	..
28	*Teredo*, sp.	×	..	..	..
29	*Thracia karquinesensis*, n. sp.	..	×	..	..
30	*Actaeon lawsoni*, n. sp.	×	..	×	..
31	*Ampullina* (conf.) *striata* Gabb	..	×	×	×
32	*Brachysphingus liratus* Gabb	..	×	×	×
33	*Bullinula subglobosa*, n. sp.	..	×	..	..
34	*Cylichna costata* Gabb	×	..	..	×
35	*Dentalium cooperi* Gabb	×	×	..	×
36	*Dentalium stramineum* Gabb	..	×	..	..
37	*Discohelix californicus*, n. sp.	×	..	..	..
38	*Ficopsis angulatus*, n. sp.	..	×	..	..
39	*Fusus aequilateralis*, n. sp.	×	..	..	..
40	*Heteroterma gabbi* Stanton	..	×	..	×
41	*Heteroterma striata* Stanton	..	..	..	×
42	*Heteroterma trochoidea* Gabb	..	×	..	..
43	*Heteroterma*, indet.	..	×	..	..
44	*Lunatia hornii* Gabb	..	..	..	×
45	*Megistostoma striata* Gabb	..	×	..	..

		Lower beds at Martinez.	Upper beds at Martinez.	Benecia.	Lake County.
46	*Morio tuberculatus* Gabb	..	×	..	..
47	*Natica*, sp.	..	×	..	..
48	*Neptunea mucronata* Gabb	×	..	..	..
49	*Perissolax tricarnatus*, n. sp.	×	×	×	×
50	*Perissolax blakei* Gabb	..	..	×	..
51	*Siphonalia lineata* Stanton	×	×	..	×
52	*Architectonica tuberculata*, n. sp.	..	×	..	..
53	*Strepsidura pachecoensis* Stanton	..	×	..	..
54	*Tritonium impressum*, n. sp.	..	×	..	..
55	*Tritonium eocenicum*, n. sp.	..	×	..	..
56	*Tritonium pulchrum*, n. sp.	..	×	..	..
57	*Turbinella crassitesta* Gabb	×	..	..	..
58	*Turritella infragranulata* Gabb	..	×	×	×
59	*Turritella pachecoensis* Stanton	..	×	..	×
60	*Turritella conica*, n. sp.	..	×	..	..
61	*Turris*, sp. indet.	..	×	..	..
62	*Urosyca caudata* Gabb	×	×	×	×
63	*Urosyca robusta*, n. sp.	×	..	..	..
64	*Xenophora zitteli*, n. sp.	×	..	..	..
65	*Cancer*, (?) sp.	..	×	..	..
66	Crustacean remains, macruran	..	×	..	..
67	*Serpula*	×	..	..	..

CORRELATION.

Because of the somewhat divergent views held by various writers in regard to the correlation of the different divisions of the Eocene in other parts of the world, and owing to the fact that a large majority of the species occurring in the Pacific Coast Eocene are not represented elsewhere, it becomes extremely difficult to make a correlation of the Eocene of the West Coast with other sections. In 1898 Dr. W. H. Dall* drew up a correlation table of the American and European Eocene. In this paper he represents the combined Eocene of the Pacific Coast as the equivalent of the Midway stage of the Atlantic and Gulf States, and of the Cernaysian of Europe. Thus, according to his views, the Martinez and Tejon groups, taken together, form the lower Eocene. Since in this case no use can be made of species, as there are none common to other regions, it is necessary to base correlation on the maxima of genera. For comparison with the Martinez fauna the following important localities have been selected; the Gulf states, the Atlantic states, the London and Paris Basins and the Sind district of Western India.

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*18th Ann. Rept. U. S. Geol. Survey, Pt. 2, pp. 327-348, 1898.

Compared with these, the fauna of the Martinez Group is seen to be a distinct unit. Of the forty-nine genera listed, only twenty-two could be found in the literature on the Eocene of the Gulf and Atlantic states. No species were found in common, yet several were somewhat similar. This fauna has its closest affinities with that represented in the Midway of the Gulf states and the Aquia stage of Maryland and Virginia. The correspondence to the Aquia is, however, less marked than to the Midway. Professor Clark* considers the Aquia and Nanjemoy together to represent both the upper and lower substages of the Chickasawan of the Gulf states, and also he considers it questionable whether the Eocene is represented by any beds in the Middle Atlantic slope older than the Chickasawan. The fauna of the Tejon group bear a closer similarity to both the Aquia and Chickasawan than does the Martinez. Since the Tejon overlies the Martinez, it would seem very probable that if any correlation of the latter can be made at all, it would best be made with a portion of the Midway as represented in the Gulf states, and with that portion of the lower Eocene which is not represented in the Maryland and Virginia regions. Hence, the Martinez may represent some portion or all of the lower quarter of the Eocene.

The similarity of the Martinez fauna to that of the London and Paris Basins is less marked. Sixteen out of the forty-nine genera are common to the Eocene of the London Basin, and the fauna corresponds more closely to that of the Thanet Sands or lower Eocene. Fifteen genera were found corresponding to those in the Eocene of the Paris Basin, and bore the closest resemblance to the Bracheux beds, which are considered to be lower Eocene.

In the Eocene fauna listed by Mr. W. T. Blanford† in his memoir on the Geology of the Western Sind, nine genera, but no species, were found which occur also in the Martinez group.

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*Rept. Maryland Geol. Sur. Eocene. W. B. Clark, p. 84, 1901.

†Memoirs of the Geological Survey of India, Vol. XVII, pp. 1-200, 1880.

The genera represented in both resembled most closely the fauna of the Ranikot group. This group is supposed to belong to the lower Eocene. The small number of common forms indicates that there was probably no direct faunal connection between India and the Western Coast of North America in Martinez times. The same view is arrived at by Professor J. P. Smith*, in which he states "in the upper Chico horizon of California and Oregon the connection with India appears to cease," and "during the early Tertiary or Tejon epoch in California we have no evidence of any migration from Asia." The evidence seems also to point to the fact that during this period the Martinez seas were isolated from the regions of the southeastern United States. Later, during the Tejon, a passage was possibly opened.

Although these localities are widely separated, and only a small proportion of the genera is common, yet there seem to be sufficient distinctive forms not only to place the Martinez Group in the Eocene, but also to show that it represents a portion or all of the lower quarter of the Eocene.

SUMMARY.

From the foregoing discussion it is evident that the Martinez represents a distinct division of time in the geological history of Calfornia. It contains a fauna distinct from both the Chico and the Tejon. On the average it is composed of about two thousand feet of thick-bedded sandstones, together with some shales. thin-bedded sandstones and conglomerates. Its geographical extent as at present known is confined to southern Lake County and a belt extending north and south across the Strait of Karquines. Its position in the geological scale seems to correspond most closely to a portion or all of the lower quarter of the Eocene.

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*Periodic Migrations between the Asiatic and the American Coasts of the Pacific Ocean, by J. P. Smith. Am. Jour. Sci., Vol. XVII, p. 224, 1904.

DESCRIPTION OF SPECIES.

PELECYPODA.

Lima multiradiata GABB.

Lima multiradiata Gabb, 1869, Palaeontology of California, Vol. II, p. 201, Pl. 33, fig. 101.

This shell is large, moderately convex and only slightly oblique. The posterior side forms an irregular curve from the ear to the base. The anterior margin is concave from the ear to a point midway to the base, and is regularly convex below that point. The surface is covered with numerous radiating ribs, each of which in the vicinity of the margin is narrower than the interspaces. These ribs have a somewhat wavy appearance. The surface is also marked by several large and numerous smaller well defined lines of growth.

Dimensions:—The measurements of two specimens are given. The maximum height of a cast of the first is 92 mm. Its greatest width is 88 mm. The second specimen, also a cast, has a maximum length of 106 mm. and a width of 96 mm. The margins of both these specimens are more or less broken away. When restored the maximum width of the casts would about equal the distance from beak to base. These shells closely resemble *Lima multiradiata* Gabb as described by Stanton from Lower Lake. They differ in that they are less oblique and much wider. The width is one-third greater in proportion to the distance from beak to base than in the case of *Lima multiradiata* as described by Stanton. Although somewhat different in form, it seems best to consider these specimens as *multiradiata*.

Occurrence:—This form occurs about three miles to the southwest of Martinez, in the hills to the west of Del Hambre Cañon. As yet it has been found only in the lower half of the Martinez Group.

Modiola merriami, n. sp.

PL. 12, FIG. 2.

The shell is thin, elongated and moderately convex. The beaks are broad and not very prominent. The umbonal ridge is prominent, rounded, and curved only slightly downward. The surface is marked by several rather prominent concentric wrinkles. There is no radial ornamentation.

Dimensions:—The maximum length is 30 mm. and the greatest width 15 mm.

Occurrence:—This form has been found about three miles southwest of the town of Martinez, associated with *Lima multiradiata.* It also occurs about three miles south of Martinez, on the east side of the road leading to Walnut Creek. It is characteristic of both the upper and the lower Martinez beds.

Arca biloba, n. sp.

PL. 12, FIG. 4.

The shell is strongly arched, moderately inflated and inequilateral. The beaks are small, incurved and grooved. From the interspace between the two heads of the beak there runs a moderately deep groove over the surface of the shell toward the base. The beak is located about one-third the distance from the anterior end. The anterior end is somewhat narrow. The posterior end is obliquely truncated. The base is broadly rounded. Behind the umbonal ridge the surface is nearly flat. The surface is marked by numerous ribs, and these are crossed by many regular lines of growth.

Dimensions:—The maximum length of the specimen described is 9.5 mm., and the greatest width 3.5 mm.

Occurrence:—This shell has been found about three miles southwest of Martinez, in association with *Lima multiradiata,* and also about five miles southwest, near the head of Vaca Canon. It occurs in both the upper and lower beds.

Tellina martinezensis, n. sp.

PL. 12, FIG. 3.

The shell is small, thin, compressed, and about twice as long as the distance from the beak to the base. The anterior end is rather broad. The posterior end is considerably narrower and truncated obliquely. The beaks are small and nearly central. The basal margin is convex. A ridge, especially well marked near the beak but gradually becoming fainter toward the base, passes from the beak to the posterior basal angle. The surface is ornamented by numerous small, regular, concentric lines.

Dimensions:—The maximum length is 21 mm., and the greatest breadth is 14 mm.

Occurrence:—This specimen was found about two miles south of Martinez, on the east side of the road reading to Walnut Creek. It occurs in both the upper and lower beds.

Solen stantoni, n. sp.

PL. 12, FIG. 1.

The shell is thin, elongated and moderately convex. The cardinal and basal margins are nearly parallel. The beaks are anterior. The base is straight and the ends somewhat rounded. The posterior end is more abruptly truncated than the anterior. The surface is marked by faint concentric lines of growth. Passing down from the beak to the base of the anterior margin there is on each side a deep, sharp constriction which is nearly at right angles to the hinge line.

Dimensions:—The maximum length of the type specimen was found to be 50 mm. The greatest width is 7 mm.

Occurrence:—This form has been found at several localities in Contra Costa County. It is most common about four miles south of Martinez, on the west side of the road to Walnut Creek and near the mouth of Vaca cañon. As yet it has been found only in the upper beds.

Pholadomya nasuta GABB.

PL. 12, FIG. 6.

The specimen which was described in Volume I, Palaeontology of the California State Geological Survey, is distorted, and hence the drawing does not represent the normal form. In the distorted specimen the beak is too high and narrow and the lip slants inward from beak to base. Such is not the case in normal forms which are now known from perfect specimens.

This shell is considerably inflated, beaks moderately high, broad and prominent. Anterior ends incurved and approximated. The posterior end is produced and rounded. The anterior end is inflated and sharply truncated. The surface is marked by about fourteen strong radiating ribs, which are present only on the middle of the shell. Numerous prominent concentric ribs extend to the shell margin. The base and the anterior end are closed and the posterior end gapes considerably. The lip extends slightly outward in the upper half and then is obliquely truncated inward toward the base.

Dimensions:—The length of the specimen described is 69 mm. The maximum thickness is 37 mm., and the distance from beak to base 46 mm.

Occurrence:—This species is found at numerous localities south of Martinez; also on the arsenal grounds at Benicia. It is characteristic of both upper and lower beds.

Thracia karquinesensis, n. sp.

PL. 12, FIG. 5.

The shell is thin, moderately convex and marked with concentric striæ. The beaks are prominent and located about one-third the distance from the anterior end. The base is nearly straight. The upper margin of the wing is nearly parallel to the base. The anterior end is rounded and the posterior somewhat produced, the body of it where it joins on to the wing sloping downward toward the base and making an angle of about forty-five degrees.

Dimensions:—The maximum length of this specimen is 29 mm., and the distance from beak to base 15 mm. Only one specimen has been found.

Occurrence:—This form was found about two and one-half miles south of Martinez, on the west side of the road to Walnut Creek. It occurred in the upper beds of the Martinez.

GASTEROPODA.

Architectonica tuberculata, n. sp.

PL. 12, FIGS. 7 & 7*a*.

The shell is small, the spire low, and the number of slightly convex whorls present is six. The surface is marked by a number of small tubercular ribs. There are eight ribs to each whorl. This description is taken from a cast.

Dimensions:—The diameter was found to be 9 mm., and the distance from base to apex 2 mm.

Occurrence:—The locality is about two and one-half miles south of Martinez, on the west side of the road to Walnut Creek. It occurs only in the upper Martinez beds.

Discohelix Californicus, n. sp.

Pl. 12, Fig. 9.

The shell is of the typical discohelix form. The number of whorls is five. The characteristic angles are sharp, especially on the outer whorl. The first whorl is more prominent on the upper than on the lower side. The upper side of the shell is flat to slightly concave. The surface is smooth and the aperture nearly square.

Dimensions:—The specimens are not perfectly circular, due to distortion. The maximum diameter is 21 mm. and the minimum diameter of the same specimen 19½ mm. The width of the outer whorl is 4.5 mm.

Occurrence:—It is most common about four miles to the southwest of Martinez, on the west side of the Del Hambre Cañon road. It occurs in the lower beds only.

Turitella conica, n. sp.

Pl. 13, Fig. 2.

The shell is moderate in size and rather robust. The number of whorls present is nine. They increase rapidly in size and are flat to slightly convex on the outer face. The suture is impressed. Each whorl is marked by five distinct, equidistant, revolving ribs, the lower three of which are very prominent. Between these are several fine striæ. The aperture is subquadrate.

Dimensions:—The maximum length of the specimen described is 18 mm. The maximum diameter is 7.5 mm.

Occurrence:—It is common on the west side of the road between Martinez and Wanut Creek, about three miles south of Martinez.

Xenaphora zitteli, n. sp.

Pl. 12, Fig. 8.

Three specimens have been found. The largest of these has seven nearly flat whorls. The spire is low. The base is nearly flat. The aperture is obliquely quadrilateral. A line joining the outer edge of the last whorl with the apex makes an angle of about forty-five degrees with the base. The whorls are covered with extraneous objects, which appear to be pebbles of quartz ranging up to 15 mm. or more in diameter.

Dimensions:—The diameter of the type specimen is 87 mm. Height from apex to base, 57 mm.

Occurrence:—Found southwest of Martinez, on the west side of the Del Hambre Cañon road. This species occurs only in the lower beds of the Martinez group.

Ficopsis angulatus, n. sp.

PL. 13, FIG. 5.

Spire low, with four or five angular whorls. The body whorl is marked by three prominent equidistant angles which distinguish it from *Ficopsis remondi*. The surface between the angles is concave. The surface of all the whorls is marked by numerous sharply defined fine revolving lines and linear ribs which cut it into minute squares. The space between these ribs is concave to flat.

Dimensions:—Maximum length from base to apex is 6 mm. The greatest width is 4 mm.

Occurrence:—About three miles south of Martinez, on the east side of the road to Walnut Creek. It occurs only in the upper beds.

Urosyca robusta, n. sp.

PL. 13, FIG. 1.

The spire is very low. The whorls number six. On the body whorl there are four very prominent and nearly equidistant nodose revolving ribs. On the lower part of the body whorl there are numerous fine revolving striae. The aperture is broad. The canal is long and from the impression in the matrix appears to be slightly twisted. This species differs from *Urosyca caudata* in the constant presence of a fourth revolving nodose rib.

Occurrence:—This species occurs near the base of the beds. *Urosyca caudata* has been found in both divisions of the Martinez. Found southwest of Martinez, on the west side of the road through Del Hambre Cañon.

Tritonium impressum, n. sp.

PL. 13, FIG. 3.

The shell is moderately long. The spire is elevated. The number of whorls is five. The second whorl is about one-third the height of the body whorl. The surface of the whorls is moderately convex. The mouth is broad. The suture is deep. The surface is marked by numerous small longitudinal ribs. The varices are moderately large but few.

Dimensions:—The distance from base to apex is 28 mm., and the maximum width of the body whorl 14 mm.

Occurrence:—Three miles southwest of Martinez and west of the Del Hambre Cañon road. It occurs in the upper beds only.

Tritonium eocenicum, n. sp.

PL. 13, FIG. 4.

The spire is moderately elevated. The whorls are five in number, possibly six. They support broad, prominent transverse ribs, of which there are about twelve on the body whorl. These ribs are slightly oblique and may be almost sinuous. They are about one-half as broad as the interspaces. These ribs are crossed by numerous well marked revolving striae. The few varices are well marked. Only one specimen was found.

Dimensions:—The distance, measured from apex to base, is 10 mm. The maximum width is 6.5 mm.

Occurrence:—About two and one-half miles south of Martinez, on the east side of the road to Walnut Creek. It has been found in the upper beds only.

Tritonium pulchrum, n. sp.

PL. 13, FIG. 6.

This shell is fusiform and turreted. The spire is high and the number of whorls is eight. They are sharply angulated and the slope nearly straight above. The body whorl is convex below. The surface is marked by numerous longitudinal and revolving ribs. Upon the body whorl are twenty-six revolving ribs. Nine of these were above and seventeen below the angle. The varices are very prominent, about ten in number on each whorl, and support prominent nodes on the angles of the whorls.

Dimensions:—Distance, measured from apex to base, is 34 mm. The maximum width of the body whorl is 16 mm.

Occurrence:—About two and one-half miles south of Martinez and on the west side of the road to Walnut Creek. Its geological range is confined to the upper Martinez beds.

Fusus aequilateralis, n. sp.

PL. 13, FIG. 7.

The shell is small and elongated. The whorls number six. They are very convex and prominently angulated. The upper and lower faces are equal and slightly convex. The suture is distinct. The spire is high. The canal is long and straight. The surface of each whorl is marked by nine or ten quite large nodes on the angles. This form resembles *Fusus martinezensis* very closely, but differs in the greater length of the spire, in the prominence of the angles upon the whorls, and in the nodes upon the angles.

Dimensions:—The distance, measured from apex to base, is 21 mm. The maximum width of the body whorl is 8 mm.

Occurrence:—The type specimen was obtained about five miles south of Martinez and one and one-half miles north of Grayson Creek. It occurs only in the lower beds.

Perissolax tricarnatus, n. sp.

PL. 13, FIG. 9.

Shell elongated, spire moderately elevated. Whorls six in number. The body whorl is ornamented by three prominent revolving carinae. The upper two form prominent nodose angles on the whorl and separate a slightly concave middle portion from the sharply sloping upper and lower areas. A short distance below the lower of these two angles is the third carina, which is less prominent and is scarcely nodose. The remaining whorls show only the upper carina. The aperture is elongated and narrow. The presence of the three revolving ridges on the body whorl seems to be a constant character for all specimens collected in this region, and, as no intermediate forms appear, it seems best to regard this as a new species, distinct from *Perissolax blakei* Gabb of the Tejon.

Dimensions:—The length from the broken end of the canal to the apex is 27 mm. The maximum width of the body whorl is 19 mm.

Occurrence:—Southwest of Martinez and west of the Del Hambre Cañon road. It has also been found at Benicia, on the U. S. arsenal grounds, about two hundred yards northwest of Army Point railroad station, and in southern Lake County, about one mile southeast of the town of Lower Lake. It occurs in both the upper and lower beds.

Bullinula subglobosa, n. sp.

PL. 13, FIG. 8.

The shell is small and sub-globose. The spire is low but acute. The whorls number five. The aperture is broad. The surface is marked by regular lines of growth and by numerous very fine impressed revolving striae.

Dimensions:—The height is 8 mm. and the width 5 mm.

Occurrence:—About three and one-half miles south of Martinez and west of the road to Walnut Creek. It occurs only in the upper beds.

Actaeon lawsoni, n. sp.

PL. 13, FIG. 10.

The shell is subovoid and elongated. The number of whorls is five. They are very regularly rounded. The suture is channeled. The entire surface of all the whorls is marked by numerous narrow revolving ribs. There are thirty-two ribs on the body whorl, and these are connected by numerous very minute lines. The aperture is narrow. The extremity of the columella shows distinct plications.

Dimensions:—The length from base to apex is 9.5 mm., and the maximum width of the body whorl is 6 mm. The specimens appear to be slightly compressed.

Occurrence:—Three miles southwest of Martinez and west of the Del Hambre Cañon road. It occurs only in the lower beds, but near the top of that division.

CRUSTACEA.

CANCER (Lin.) Leach.

Cancer? sp.

Pl. 13, Fig. 11.

All that remains of the specimen is a portion of the carapace, and from this it is at present impossible to determine the genus and species more accurately than to show that it closely resembles the genus *Cancer.*

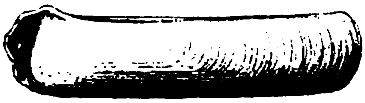
Dimensions:—The maximum breadth is 29 mm., and the length is 21 mm.

Occurrence:—About four miles south of Martinez and east of the road to Walnut Creek. It occurs in the upper beds.

University of California,
February, 1905.

EXPLANATION OF PLATE 12.

Fig. 1.—*Solen stantoni*, n. sp. Nat. size.
Fig. 2.—*Modiola merriami*, n. sp. Nat. size.
Fig. 3.—*Tellina martinezensis*, n. sp. ×1½.
Fig. 4.—*Arca biloba*, n. sp. Nat. size.
Fig. 5.—*Thracia karquinezensis*, n. sp. Nat. size.
Fig. 6.—*Phaladomya nasuta* Gabb. Nat. size.
Fig. 7.—*Architectonica tuberculata*, n. sp. ×2.
Fig. 7*a*.—Upper side of body whorl of specimen shown in fig. 7. ×5.
Fig. 8.—*Xenophora zitteli*, n. sp. ×⅔.
Fig. 9.—*Discohelix californicus*, n. sp. Nat. size.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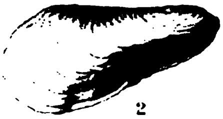
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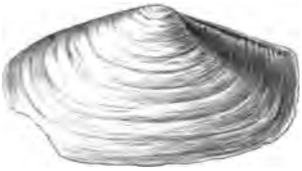
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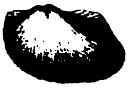
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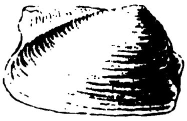
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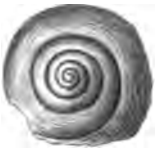
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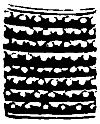
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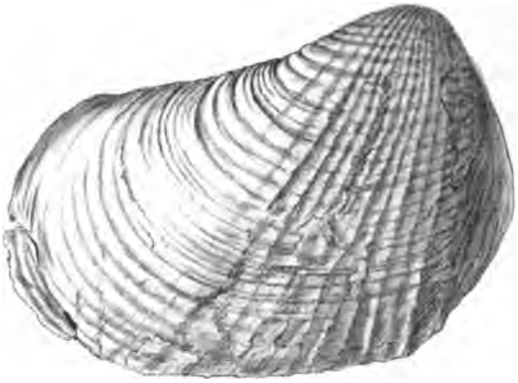
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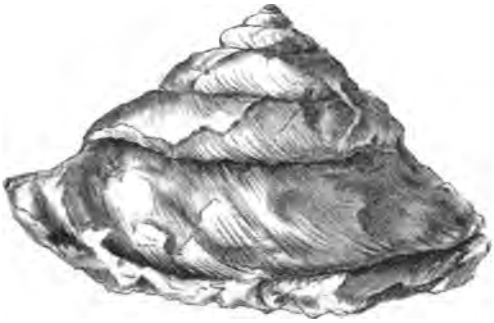
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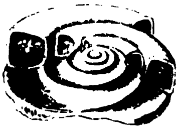
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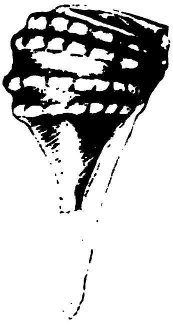
EXPLANATION OF PLATE 13.

Fig. 1.—*Urosyca robusta*, n. sp. Nat. size.
Fig. 2.—*Turritella conica*, n. sp. ×1½.
Fig. 3.—*Tritonium impressum*, n. sp. Nat. size.
Fig. 4.—*Tritonium eocenicum*, n. sp. ×2.
Fig. 5.—*Ficopsis angulatus*, n. sp. ×2.
Fig. 6.—*Tritonium pulchrum*. Nat. size.
Fig. 7.—*Fusus aequilateralis*, n. sp. ×1½.
Fig. 8.—*Bullinula subglobosa*, n. sp. ×2.
Fig. 9.—*Perissolax tricarnatus*, n. sp. Nat. size.
Fig. 10.—*Actaeon lawsoni*, n. sp. ×3.
Fig. 11.—*Cancer* (?), sp. Nat. size.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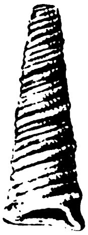
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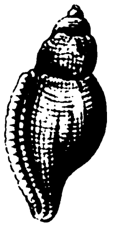
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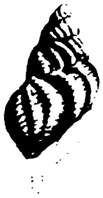
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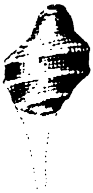
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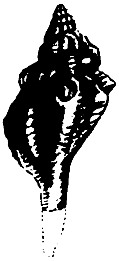
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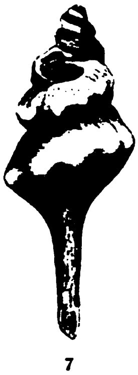
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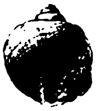
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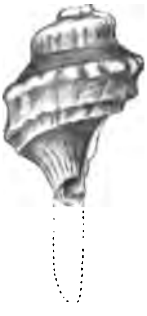
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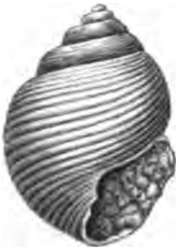
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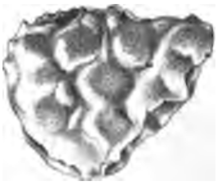
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BULLETIN OF THE DEPARTMENT OF
GEOLOGY

Vol. 4, No. 6, pp. 125-143, Pls. 14-18. ANDREW C. LAWSON, Editor

NEW OR IMPERFECTLY KNOWN RODENTS AND UNGULATES

FROM THE

JOHN DAY SERIES

BY

WILLIAM J. SINCLAIR.

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INTRODUCTION.

In the mammalian collections obtained in the John Day region by the University of California parties of 1899 and 1900 there are a number of forms which are new to science, and others which have been only imperfectly described. Of these collections Professor Merriam has turned over to the writer the ungulate and rodent material for study and description.

In the following paper no attempt is made to discuss the relations of the faunas with which the described species are associated. In a later article by Professor Merriam and the writer, there will be presented a general discussion of the relations of the series of mammalian faunas known in this region.

PEROMYSCUS PARVUS, n. sp.

Pl. 14, Figs. 4 and 5.

Type.—Portions of maxillary and mandible, No. 84, Univ. of Cal. Palaeont. Coll.

Locality.—Upper Diceratherium beds, Middle John Day. Turtle Cove, Grant Co., Oregon.

Smaller than *P. nematodon*. Upper molars with two principal and two subsidiary enamel inflections on the outer side of the tooth crown.

The first two molars of the superior series are preserved in a fragment of the left maxillary. They are low crowned and tuberculate. The subsidiary enamel inflections are situated respectively anterior and posterior to the two principal external enamel loops, and would disappear were the teeth slightly more worn. In M_1 there is one wide external and two narrower internal enamel invaginations. The second and third lower molars are represented by the roots only. The lower incisor is delicately grooved on the outer face.

MEASUREMENTS.

Length M^1 to M^2 inclusive	3.5 mm
Length M_1 to M_3 inclusive, on alveolar border	4
Length M_1 antero-posteriorly	1.5
Depth of ramus below M_1	3.3

ENTOPTYCHUS SPERRYI, n. sp.

Pl. 14, Figs. 6 and 7.

Type.—Cranium and mandible, No. 649, Univ. of Cal. Palaeont. Coll.

Locality.—Promerycochoerus beds, Upper John Day. Haystack Valley, Wheeler Co., Oregon.

Rostrum long and broad. Interorbital region concave. Superciliary ridges strongly developed, with abrupt posterior termination. Temporal ridges low, converging from the posterior extremities of the superciliary borders to form a prominent sagittal crest. Mandibular symphysis with long straight superior border separated from P_4 by a short concavity. Size large.

E. sperryi may be distinguished from *E. planifrons* by the flat forehead and absence of temporal ridges in the latter species. In *E. lambdoideus* "there is no ridge-like thickening of the supraorbital border. It presents, on the contrary, a subacute superior edge, flush with the inferior part of the same border. These edges leave the orbital border posteriorly, and converge in straight lines to an acute angle, forming two temporal ridges." [*] *E. minor* is much smaller than *E. sperryi* and the other species of the genus and like *E. planifrons* is "characterized by the perfectly flat interorbital region and the absence of temporal ridges." [†] In *E. cavifrons*, the superciliary margins "do not meet nor converge to form a sagittal crest. They are thickened, forming two subparallel ridges which are separated by a shallow concavity of the frontal bone." [‡] In *E. crassiramis* the "internal orbital walls are rolled inward at the supraorbital region so as to meet at a point opposite the posterior border of the orbital space. Opposite the anterior part of the orbit, the ridges are more widely separated, so that the interspace is a narrow wedge-shaped fossa, opening forwards." [§] Temporal ridges are wanting and the sagittal crest is weak. The mandible differs from *E. sperryi* in the absence of the long horizontal symphysial border characteristic of that species. In *E. crassiramus* the superior mandibular border between the base of the incisor and the alveolus of P_4 is broadly concave.

The new species is named in honor of its discoverer, Mr. J. C. Sperry.

MEASUREMENTS.

Length of skull, supraoccipital to premaxillae inclusive	50 mm
Interorbital width	6.5
Width across zygomatic arches	35
Width of median portion of rostrum	11
Depth of rostrum at incisive foramina	9.5
Length of rostrum from base of P_4 to anterior end of premaxillae	24.5
Length of nasals, approximate	23.5
Length P^4 to M^3 inclusive, on alveolar border	11
Length P_4 to M_3 inclusive, on alveolar border	8.5
P^4, antero-posterior diameter	2
P^4, transverse diameter	2.5
M^1, antero-posterior diameter	2
M^1, transverse diameter	3

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[*] E. D. Cope. Tertiary Vertebrata, p. 861.

[†] *Ibid.*

[‡] E. D. Cope, *ibid.*, p. 862.

[§] E. D. Cope, *ibid.*, p. 864. Pl. LXIV, Fig. 5a.

M^3, antero-posterior diameter	1.5mm
M^3, transverse diameter	2
P$_4$, antero-posterior diameter	2.5
P$_4$, transverse diameter	2
M$_1$, antero-posterior diameter	1.75
M$_1$, transverse diameter	2.25
M$_3$, antero-posterior diameter	2
M$_3$, transverse diameter	2

ENTOPTYCHUS ROSTRATUS, n. sp.

Pl. 14, Figs. 8 and 9.

Type.—Cranium, No. $\overline{1651}$, Univ. of Cal. Palaeont, Coll.

Locality.—Promerycochoerus beds, Upper John Day. Haystack Valley, Wheeler Co., Oregon.

Skull and rostrum longer than in any other described species of *Entoptychus.*

Compared with *E. sperryi,* the rostrum is not only longer but deeper, although the width is the same. The nasals are narrow posteriorly and are not separated by a frontal process. Anteriorly they are as wide as in *E. sperryi.* The interorbital region is imperfectly preserved and it is not possible to determine its character. The upper teeth are badly worn. P^4 is apparently the largest tooth in the superior series, the molars decreasing in size posteriorly.

The specific name refers to the great length of the rostrum.

MEASUREMENTS.

Length of skull, supraoccipital to premaxillae inclusive	55.5mm
Interorbital width, approximate	7
Width at middle of rostrum	11
Depth of rostrum at incisive foramen	11
Length of rostrum from base of P^4 to anterior end of premaxillae	27.5
Length of nasals	27.5
Length P^4 to M^3 inclusive, on alveolar border	9
P^4, antero-posterior diameter	2.2
P^4, transverse diameter	2
M^1, antero-posterior diameter	1.9
M^1, transverse diameter	2

HYPERTRAGULUS, sp.

Pl. 14, Fig. 3.

All doubt regarding the inferior dental formula of *Hypertragulus* is removed by the specimen illustrated on Plate 14, Fig. 3, (No. $\overline{1343}$, Univ. of Cal. Palaeont. Coll.) from the Promerycochoerus beds on Rudio Creek, Grant Co., Oregon. Three small incisors and an incisiform canine are represented by roots. The crowns and a portion of the adjacent alveolar border have not been preserved. P_1 was functional as a canine. Its crown is unfortunately missing. P_2 is also broken off, but the roots remain and are separated by long diastemata from P_1 and P_3. Small ledge-like cuspules are present on the sides of the outer molar cresents and in the intervening valleys, except in M_3 where they are developed only on the antero-external crescent and in the valley behind it. There is but one mental foramen, situated anterior to P_2. In the specimen figured by Scott*, there is an additional mental foramen below P_3, and the mandible is somewhat deeper than in No. 1343. The posterior portion of the ramus is not preserved and has been restored in outline, together with the crown of the canine, to correspond with Scott's figure.

MEASUREMENTS.

Length I_1-M_3 inclusive	61 mm
Length P_3-M_3 inclusive	35
Length of diastema behind P_2	3.5
Depth of ramus at middle of P_3	9

ALLOMERYX PLANICEPS, n. gen. and sp.

Pl. 14, Figs. 1 and 2.

Type.—Cranium, No. 104, Univ. of Cal. Palaeont. Coll. The cranium lacks the portion anterior to P^2 and is without mandible.

Locality.—Diceratherium beds, Middle John Day. Turtle Cove on the South Fork of the John Day, Grant Co., Oregon.

Distinctive Characters.—Dentition $\frac{?}{}, \frac{?}{}, \frac{3?}{}, \frac{3}{}$. P^3 three rooted. P^4 with inner and outer crescents. Molars without mesostyle, external ribs prominent and about equally developed. Metastyle on M^3 much produced. Forehead flat. Sagittal crest low and not elevated above interorbital plane, terminating posteriorly in a prominent triangular knob. Brain case well rounded at sides, somewhat flattened above. Orbits prominent and completely inclosed with strongly developed frontal and jugal processes. A prelachrymal vacuity present. Bullae small, with outgrowth of petrosal between bulla and basioccipital.

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* W. B. Scott. Trans. Wagner Free Inst. Sci., Vol. VI, Pl. 1, Fig. 3.

Cranium.—The cranium had suffered considerably from weathering previous to the discovery of the specimen, and lacks all of the region anterior to P^2 and parts of both jugal arches. Superiorly the forehead is broad and flat, slightly domed posteriorly along the line of the median suture. The temporal ridges unite at about the anterior third of the length of the brain case to form a sagittal crest, which does not rise above the frontal plane and terminates posteriorly in a prominent triangular knob. The brain case is somewhat flattened above and moderately constricted back of the orbits. The lateral walls are well rounded. Above each orbit is a small supraorbital foramen from which a shallow groove extends anteriorly.

The back of the skull is narrow above, where the supraoccipital forms the posterior border of the knob-like occipital crest. A narrow median keel is present but fades out toward the upper border of the foramen magnum.

In the lower view (Pl. 14, fig. 2) the bullae are seen to be small, resembling those of *Leptomeryx.* They are separated from the basioccipital by a prominent outgrowth of the petrosal. Anterior to the bullae, a large foramen appears to represent the conjoined foramen rotundum and foramen ovale, but as the skull is somewhat fractured in this region the confluence of the two foramina can not be fully verified. A foramen of considerable size occupies the interval between the inner end of the postglenoid process and the bulla. The posterior palatine border has been somewhat crushed and the outlines are slightly restored in the figure.

In the lateral aspect of the cranium (Pl. 14, fig. 1) the orbits are seen to be large and entirely enclosed. The frontal and jugal processes overlap, but are not completely fused. The jugal border is more prominent than the frontal, indicating that the eye faced upward. The lachrymal and anterior frontal borders of the orbit are mammilated. A prelachrymal vacuity is present. This portion of the skull has suffered from weathering and the exact border of the vacuity is not well shown in the figure, but the rounding of the unfractured free edges of the maxillary and lachrymal may be seen with the aid of a lens.

Dentition.—The teeth are short hypsodont and are well worn, indicating the fully adult and somewhat aged condition of the animal. Only the posterior root of P^2 is represented. P^3 is supported by three roots, but the crown is too poorly preserved to permit description. P^4 is composed of two crescents, an outer and an inner. The molars are without mesostyle, with the external ribs prominent and about equally developed. In M^3 the metastyle has considerable posterior prolongation extending above the alveolar border as a lamina of the postero-external root.

Affinities.—The new genus finds its closest affinities among the Hypertragulidae, in which family it may be placed. The skull is larger than in *Hypisodus* and of a different shape. The bullae are much smaller, approximating in size those of *Leptomeryx*. It may be distinguished from *Leptomeryx* by the complete closure of the orbit, the flatness of the top of the skull and the projecton of the petrosal between the bullae and the basioccipital. In *Leptomeryx*, the bulla is "separated, as in the deer, from the basioccipital by a large reniform foramen within which a portion of the petrosal is visible." *A mesostyle is present on the molars of *Leptomeryx*, and there is no posterior extension of the metastyle on M^3 comparable to the structure developed in *Allomeryx*.

Hypertragulus agrees with the new genus in the absence of mesostyle, but the orbit is incompletely closed and jugal processes are wanting. † The brain case is not as long as in *Allomeryx*,‡ and there is no extension of the petrosal on the inner side of the bulla. In *Allomeryx* the interorbital tract and the superior border of the sagittal crest lie in the same plane. This is not true for the other members of the Hypertragulidae. The palatine region also differs from both *Leptomeryx* and *Hypertragulus*. In neither of these genera does the palatal border of the nares extend anteriorly between the posterior molars as in *Allomeryx*.

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* J. Leidy, Ext. Mamm. Fauna of Dakota and Nebraska, p. 168 and Pl. XIV, fig. 4.

† W. B. Scott, Trans. Wagner Free Inst. Sci., Vol. VI, p. 18, 1899.

‡ Compare Pl. 14, fig. 2, with Scott, *op. cit.*, Pl. 1, fig. 4.

Measurements.

Basilar length of cranium from the anterior border of the alveolus of P^3 to condyle inclusive	79.5 mm
Width between superior orbital rims	42
Length of sagittal crest from point of confluence of temporal ridges	29
Depth of skull to alveolar border through middle of orbit	33
Length from point of union of temporal ridges to fronto-parietal suture	11
Antero-posterior diameter of orbit	26.5
Transverse diameter of orbit	21
Width of brain case at postorbital constriction	30
Greatest width of brain case	35.5
Width of palate at M^3	22.5
Length P^3-M^3 inclusive	31
Length M^1-M^3 inclusive	22
M^1, greatest antero-posterior diameter	6.5
M^1, transverse diameter on triturating face through anterior crescents	7
M^2, greatest antero-posterior diameter	7
M^2, transverse diameter on triturating face through anterior crescents	8
M^3, greatest antero-posterior diameter	9
M^3, transverse diameter on triturating face through anterior crescents	9

ELOTHERIUM CALKINSI, n. sp.

Pl. 15.

Type.—Cranium and mandible, several cervical vertebrae and portions of fore and hind limbs, No. 953, Univ. of Cal. Palaeont. Coll.

Locality.—Upper part of the Promerycochoerus beds, Bridge Creek, Wheeler County, Oregon.

Chin rounded, without knob-like bosses. Posterior mandibular protuberances small and hollow. Jugal processes plate-like, with thickened rib, directed posteriorly, not extending below inferior mandibular border. Size large.

The teeth are greatly worn and partially shed, with closure of the alveoli, indicating the extreme senility of the individual. P^1 to P^3 are double-fanged, with simple, laterally compressed crowns. P^1 is separated from the canine by a short diastema (9.5 mm). Between P^1 and the alveolus of P^2 there is a considerably greater interval (27 mm). In the figure (Pl. 15) P^2 is not shown, as this tooth has been shed from the left maxillary. P^3 is in practically continuous series with P^4 and the molars. P^4 is supported by three roots. The crown has two cusps, a protocone and a deuterocone and there is a strong external cingulum. The pattern of of the anterior molars is entirely obscured by wear. Anterior and posterior cingula are rather prominently developed. M^3 was found separate in the matrix. In this tooth the broad dome-shaped hypocone is unworn, while the remaining cusps are much reduced. There is a broad anterior cingulum, but no posterior cingulum is observable.

In the mandible, P_1 has been shed on either side and the alveolus closed. P_2, preserved only on the right ramus, resembles the smaller premolars of the upper series. P_3 has been shed, the alveolus on the right side only remaining open. Anterior and posterior cingula are well developed on the lower molars. In M_3 the hypoconulid is not differentiated from the posterior cingulum, which projects slightly forming a very small heel.

The right side of the cranium has been badly crushed. The left side is less distorted. The chief point of specific value attaching to the cranium is in the shape and direction of the jugal processes. These processes are plate-like with a thickened median rib. The free edges, especially the anterior, are thin and sharp. The processes are short, not extending below the lower mandibular border. The orbits are posterior in position, their anterior borders lying above the posterior edge of M^3.

The mandible is peculiar in the absence of the knob-like bosses on the chin, which are so prominently developed in *E. ingens* and *E. imperator.** The protuberances beneath P_4 are small and deeply cupped. The dependent angle slopes gradually backward without the abrupt downward curvature characterizing *E. ingens.*

With the skull were preserved the atlas, axis and three anterior cervicals, all considerably crushed, fragments of a radius, an imperfectly preserved tibia, an astragalus, the right and left unciform and navicular, the left pyramidal, the fused ecto-mesocuneiform, a scaphoid, a third metatarsal and a phalanx. These do not differ sufficiently from *E. ingenus* as described by Scott to warrant separate description here.

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* W. B. Scott, The Osteology of Elotherium. Trans. Am. Phil. Soc., Vol. XIX, p. 285.

The species is named in honor of its discoverer, Mr. Frank C. Calkins.

But one other complete skull of *Elotherium* has been obtained from the John Day. A number of years ago Messrs. Leander S. Davis and William Day, while collecting for Professor Marsh, discovered a perfect cranium in the lower Diceratherium beds in the Blue Basin, Turtle Cove. This specimen, now in the Marsh collection at Yale University, is a distinct species.

MEASUREMENTS.

Total length of skull	**616 mm**
Length of mandible	**560**
Length P^1-M^3 inclusive, on alveolar border	**280**
Length M^1-M^3 inclusive	**97**
Length M_1-M_3 inclusive	**105**
Depth of mandible below P_2	**78**
Depth of mandible below M_1	**109**
P^3, antero-posterior diameter	**37.5**
P^4, antero-posterior diameter	**25.5**
M^1, antero-posterior diameter	**31.5**
M^1, transverse diameter	**33**
M^2, antero-posterior diameter	**33**
M^2, transverse diameter	**33.5**
M^3, antero-posterior diameter	**31**
M^3, transverse diameter	28
M_2, antero-posterior diameter	35
M_2, transverse diameter	29
M_3, antero-posterior diameter	34
M_3, transverse diameter	26
Length of third metatarsal	168
Length of astragalus	76
Width across proximal end of astragalus	42

THINOHYUS (BOTHROLABIS) DECEDENS Cope.

Pl. 16.

Chaenohyus decedens Cope. Pr. Am. Phil. Soc., Vol. XVIII, p. 373, 1879, Vol. XXV, p. 63, 1888.

Type.—Cranium in the Condon collection, Eugene, Oregon. Mandible, No. 1989, Univ. of Cal. Palaeont. Coll. The mandible is associated with part of a cranium in which I^3, part of the canine, P^4 and Ms^{1-3} are preserved.

Locality.—Diceratherium beds, Middle John Day. Near McAllister's ranch, below Twickenham, Wheeler Co., Oregon. The specimen was recovered from a horizon situated about fifty feet above the top of the Lower John Day.

Specific characters.—Facial region shortened, profile concave. Forehead convex. Molars rapidly increasing in diameter posteriorly, with strongly mammilated enamel. M^3 with large antero-internal style and prominent postero-internal heel. Inferior dental series interrupted by a diastema on either side of P_2.

Two speciemens have been referred to this species. In addition to the imperfect cranium associated with the mandible which has been taken as the type of the inferior dentition, there is in the University collection a much more perfectly preserved cranium (No. 556) collected by Mr. L. S. Davis from the middle of the Diceratherium beds below Sheep Rock, in Butler Basin, Grant Co., Oregon. This specimen, combined with mandible No. 1989 is figured on Plate 16.

Generic position.—*Thinohyus decedens* was placed by Cope in a distinct genus, *Chaenohyus,* which he distinguished from his *Bothrolabis* by the presence of three superior premolars in the former and four in the latter. The type of *Chaenohyus* has been examined by Professor Merriam, to whose notes the writer is indebted for the following particulars. The first superior premolar is a double-rooted tooth situated inside the base of the canine at a distance about equal to its own diameter, and reaching about as far forward as the posterior margin of that tooth. Posterior to P^1, of which the base is preserved, the alveolar border is somewhat broken, but there is a small alveolus close to that for the anterior root of P^3. The dental formula is therefore the same as in *Bothrolabis,* and the two genera must be regarded as identical.

The writer has examined the type of Marsh's *Thinohyus,* which was proposed* for the reception of two porcine species from the John Day,*T. lentus* and *T. socalis,* and is unable to distinguish *Bothrolabis* from it. *Bothrolabis* is therefore bracketed as a probable synonym. An imperfectly preserved mandible (No. 1990) from the the Diceratherium beds near Price, in the Crooked River Basin, Crook Co., Oregon, corresponds fairly well in the spacing of the lower premolars and in size with *T. lentus* and has been referred to that species in our list of the fauna from the Diceratherium beds.

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* O. C. Marsh, Am. J. Sci., 3d Ser., Vol. IX, pp. 248-249, 1875.

Cranium.—Anterior to the orbit the facial region is abruptly contracted both laterally and vertically. This feature is peculiar to *T. decedens.* In the remaining species the facial region is of the elongated type of *T. osmonti* (Pl. 17). Between the orbits, the forehead is convex, without elevated superciliary borders. A pair of broad grooves diverging anteriorly extend forward from the supraorbital foramina. They are separated by a low ridge. The median ridge and the grooves are minor features and do not materially affect the general convexity of the forehead. The palate is flat. There is but little downward curvature of the premaxillae, in striking contrast with *T. osmonti* and *Dicotyles.* The premaxillary border of the anterior nares has been fractured on either side and is restored in the figure.

Mandible.—Portions of both rami are preserved with cranium No. $\overline{1989}$. The left ramus represented in Plate 16 is the better preserved. It increases in depth posteriorly. There are four mental formina observable, one slightly posterior to P_2, two beneath P_4 and one beneath the anterior half of M_1.

Dentition.—The crowns of the first pair of superior incisors are not preserved in either specimen. The second pair resemble the corresponding teeth in *Dicotyles.* The third pair, preserved in cranium No. $\overline{1989}$, are long and pointed and considerably recurved. The canines are broad blades, triangular in cross-section with the apex of the triangle directed posteriorly. The outer face is marked by two ridges, the posterior much stronger than the interior. P^1 is double rooted and is situated on the inner side of the base of the canine. In the figure, it is represented as having slipped from the alveolus. As preserved, the extension of this tooth below the alveolar border does not exceed the length of P^2. P^2 is like the first, but larger. P^3 carries a large postero-internal basin-shaped heel. In addition to protocone and deuterocone, the tritocone is more or less developed in P^4. There are short diastemata anterior and posterior to P^1, but the rest of the superior dentition is in close series. The molars increase rapidly in diameter posteriorly. The enamel of the crowns is mammilated especially in M^3. A large antero-internal style is present on this tooth and also a prominent postero-internal heel, the surface of which supports a number of lesser tubercles. Mammilated external cingula appear on P^4 and the molars. Anterior and posterior cingula appear on P^4 and the molars. An internal cingulum is developed on P^3 and on Ms $^{2-3}$. On the latter teeth it is mammilated like the external cingulum.

The lower incisors have not been preserved. The canine is triangular in cross-section with a prominent median ridge on the outer side. P_1 is represented by a single large alveolus close to the canine. P_2 is double rooted with a simple laterally compressed crown. P_3 supports a small anterior basal cusp and a moderately broad heel. On P_4 the protoconid and deuteroconid are equally developed and separated by a deep notch. There is a broad heel with an antero-posterior ridge formed by the confluence of two small conules. The diastema between P_1 and P_2 is 6mm. in length. A somewhat shorter interval (5mm.) separates P_2 and P_3. Like those of the superior series, the lower molars increase rapidly in size posteriorly. The heel on M_3 is large, supporting a number of small cuspules, which vary in position in the same individual. External and internal cingula are developed on the heel of P_4 and at the mouths of the transverse valleys in the molars. Anterior and posterior cingula are present on P_4 and the molars. In M_3 the greatly developed heel replaces the posterior cingulum.

The only other part of the skeleton known is the calcaneum, a part of which was preserved in the matrix investing each of the two crania. It is similar to the calcaneum of *Dicotyles*, but is considerably larger.

MEASUREMENTS.

	No. $\overline{556}$	No. $\overline{1989}$
Length of cranium from anterior extremity of premaxilla to condyle inclusive	204 mm	
Interorbital width	84	
Depth of skull to alveolar border at front of orbit.	80	73.5 mm
Width of palate at P^4	27	
Width of palate at middle of M^3	25.5	
Length P^1-M^3 inclusive	79.5	81.5
Length P_1-M_3 inclusive		96
Length M^1-M^3 inclusive	46	48
Length M_1-M_3 inclusive		51
P^4, antero-posterior diameter	8.5	9
P^4, transverse diameter	9	12

	No.555	No.1989
M^1, antero-posterior diameter	12 mm	13 mm
M^1, transverse diameter	12	12.5
M^3, antero-posterior diameter	19	19
M^3, transverse diameter	16	15
P_4, antero-posterior diameter		12
P_4, transverse diameter		7
M_1, antero-posterior diameter		13
M_1, transverse diameter		9
M_2, antero-posterior diameter		22
M_2, transverse diameter		12
Approximate length of calcaneum, combined from dimensions of two specimens		61
Width of tuber calcis (dorso-plantar)		18

THINOHYUS (BOTHROLABIS) OSMONTI, n. sp.

Pl. 17.

Type.—Cranium and mandible, No. 393, Univ. of Cal. Palaeont. Coll.

Locality.—Diceratherium beds, Middle John Day. West side of the John Day Valley, about six miles north of Clarno's Ferry, Gilliam Co., Oregon.

Specific characters.—Facial region elongate, in profile an even slope from frontals to tips of nasals. Forehead flat between orbits, becoming slightly convex toward median line. Upper molars increasing little in size posteriorly. M^3 without prominent antero-internal style, with narrow heel extending as a shelf across the entire posterior border. Inferior dentition in close series. separated by a long interval from the canine.

The species is named in honor of its discoverer, Mr. V. C. Osmont.

A second specimen referable to this species was collected by Messrs. Osmont and Davis from the upper part of the Diceratherium beds on the north side of the John Day Valley at McAllister's ranch, Wheeler County, about 150 feet above the top of the Lower John Day. This specimen, a cranium without mandible (No. $\overline{1988}$), has those parts of the skull anterior to P^4 and posterior to the opening of the inferior nares broken away. The crowns of the upper teeth are much less worn than in the type specimen.

Cranium.—The facial region is greatly elongated, forming in profile an even slope from the forehead to the tips of the nasals. Between the orbits the forehead is flat, becoming slightly convex toward the frontal suture. Anteriorly there is a strongly convex swelling on either side of the median line, inclosing a deep depression which extends forward from the supraorbital foramina. The sagittal crest is thin and rises in a gentle convexity above the interorbital plane. The superciliary borders are moderately elevated. The premaxillaries are decurved to about the same extent as in *Dicotyles*. In the type specimen the maxillary is strongly rugose anterior to the base of the jugal arch. This is hardly noticeable in No. $\overline{1988}$.

Mandible.—The rami have about the same depth from P_2 to M_3, tapering anteriorly. The long and narrow symphisial region is inclined about thirty degrees to the axis of the jaw. The mental foramina are the same in number and relative position as in *T. decedens*.

Dentition.—The first superior incisor has a much broader crown than the second and third. The principal wear is on the tip and outer side of the crown. I^2 is broken, but the cross-section of its roots shows that it is a small tooth. I^3 is long and pointed and considerably compressed laterally. The upper canines are oval in cross-section at the base, but become triangular where the anterior edge is exposed to the wear of the lower canine. P^1 is a simple crowned, double-rooted tooth separated from the canine and P^2 by diastemata. Unlike *T. decedens*, P^1 is in this species situated entirely posterior to the canine, and is not overlapped by the posterior border of that tooth. It has been broken off on the side seen in the figure. The remaining superior premolars are unspaced and resemble the corresponding teeth in *T. decedens*. The upper molars increase very slightly in size posteriorly. On M^3 the heel is narrow and equally prominent on the outer and inner sides of the crown, giving to the posterior border of the tooth an even convexity. External, anterior and posterior cingula are present on P^4 and the molars. Internal cingula are feebly developed or wanting.

In the inferior series, the incisors are inclined forward in conformity with the slope of the symphysis and are worn principally on their posterior faces, although the tips of the first pair are abruptly truncated. The lower canines are triangular in cross-section, somewhat recurved, and have a strongly marked median ridge on their external faces. The lower premolars are unspaced and are separated by a long interval from the canine. All the anterior premolars are double-rooted. Unlike the superior series, the molars increase in length posteriorly. There was at least one prominent cusp on the heel of M_3. External, anterior and posterior cingula are developed on the molars.

Affinities.—*Thinohyus osmonti* may be readily distinguished from *T. subaequans* by the absence of spacing between the lower premolars and the presence of a long diastema in front of P_1. In *T. subaequans* the inferior diastemata are short and are anterior and posterior to P_1. The length of M^1-M^3 is also considerably greater in that species and the molars increase somewhat in diameter posteriorly. *T. pristinus* is characterized by a large heel on M^3 separated from the posterior cones by a valley. In the mandible of this species, P_1 is separated from P_2 and the canine by short diastemata. In *T. trichaenus* the first lower premolar is close to the canine and there are short intervals immediately anterior and posterior to P_2. In both *T. pristinus* and *T. trichaenus* the superior dental series is considerably longer than in *T. osmonti*. *T. rostratus* differs not only in the greater length of the superior dental series, but in having a longer M^3, on which the heel is extended particularly along the inner side, being nearly in a straight line with the inner border of the protocone and hypocone. It differs also in the spacing of P^2 and P^3 which are in close series in *T. osmonti*. These species are all of the type with elongated facial region. The short-faced *T. decedens* differs from *T. osmonti* in the concavity of the facial profile, the convexity of the forehead, the increase in size of the superior molars posteriorly, the rugosity of the enamel on the molars, the character of M^3, and the spacing of the lower anterior premolars. In the mandible of the more imperfectly known *T. lentus*, P_1 is separated from the canine and P_2 by diastemata of respectively 8mm. and 10mm.

MEASUREMENTS.

	No. 393
Length of skull from premaxillae to foramen magnum	225 mm
Length of mandible from anterior extremity to condyle inclusive	186
Length P^1-M^3 inclusive	79.5

	No. $\overline{393}$	No. $\overline{1988}$
Length M^1-M^3 inclusive	39 mm	42 mm
Length P_1-M_3 inclusive	81	
Length M_1-M_3 inclusive	45	
Width of skull at postorbital processes	83	
Depth of alveolar border at front of orbit	78	72
Length of diastema between lower canine and P_1 (average of both sides)	16	
Depth of mandible below P_2	33.5	
Depth of mandible below M_3	33.5	
P^4, antero-posterior diameter	10	9
P^4, transverse diameter	10.5	11
M^1, antero-posterior diameter	12.5	12.75
M^1, transverse diameter	11	11
M^2, antero-posterior diameter	13.5	14
M^2, transverse diameter	11.5	11
P_4, antero-posterior diameter	12	
P_4, transverse diameter	7	
M_1, antero-posterior diameter	12	
M_1, transverse diameter	8	
M_3, antero-posterior diameter	18.5	
M_3, transverse diameter	9	

MESOHIPPUS ACUTIDENS, n. sp.

Pl. 18.

Type.—Cranium, portion of the left fore limb, and a few vertebral fragments; No. $\overline{376}$, Univ. of Cal. Palaeont. Coll.

Locality.—Promerycochoerus beds (?), Upper John Day. Powell's ranch on the Middle Fork of the John Day River about five miles above Ritter, Grant Co., Oregon.

Superior canines long and pointed, with acute anterior and posterior edges. Metaloph hardly interrupted by metaconule, sharply separated by a deep notch from the ectoloph. Protoloph with well marked protoconule, united with ectoloph by a narrow shape-edged ridge which widens in moderately worn teeth. Parastyle broadly rounded except in M^3 where it is compressed antero-posteriorly. M^3 with metaloph storter than protoloph (*i.e.*, as 8.5 mm. : 12.3 mm.), producing almost a triangular outline for the tooth crown. Mesostyle sharply defined and ribs broadly rounded and prominent. The measurements seem also to be characteristic.

The moderately worn teeth indicate the fully adult condition of the animal. The incisors show incipient cupping and are marked by a slight depression in the center of the external face.

The long, dagger-shaped canines resemble those of a carnivore, and are quite unlike the corresponding teeth in any other known species of *Mesohippus*. The edges developed anteriorly and posteriorly are sharply set off from the rest of the tooth crown. The tips are unworn. A large hypostyle is present on all the molars and molariform premolars. On all except M^3 it gives off a narrow spur-like cingulum which borders the hypocone posteriorly. On most of the molars and premolars there are one or more small tubercles at the mouth of the transverse valley. No other traces of an internal cingulum are seen. The external cingulum is not continued across the bases of the styles.

The cranium lacks the bones investing the posterior portion of the brain case and has been somewhat crushed, accentuating the flatness of the forehead. The orbit is almost completely closed by the strongly developed postorbital process of the frontal. The supraorbital notch is entirely encircled by bone, forming a large foramen. There is a well marked preorbital fossa.

With the cranium were preserved portions of the left scapula, humerus and radius. Only the glenoid portion of the scapula is represented. It agrees with *M. bairdi* as described by Scott,[*] except that the free border of the coracoid process is bent inward, forming a rather open hook. The humerus is without a supratrochlear foramen. In this respect it differs from *M. bairdi* in which the anconeal fossa is perforate. The radius, of which the proximal portion is preserved, is very much like that of *M. bairdi*.

The specific name refers to the sharp pointed canine teeth.

The new species may be readily distinguished from the horses of the Middle and Upper White River by the dental measurements, the great length of the canine and the character of the orbital region. It approximates in dimensions *M. brachystylus* Osborn[†] from the Leptauchenia beds, but differs from that species in the shape of M^3, the form of the postorbital process and the closure of the supraorbital notch.[‡]

---

[*] Osteology of Mesohippus and Leptomeryx. Jour. of Morphology, Vol. V, No. 3, p. 319.

[†] New Oligocene Horses. Bull. Am. Mus. Nat. Hist., Vol. XX, pp. 167-179, 1904.

[‡] Compare Pl. 18 with Osborn, *op. cit.* Pl. V, E.

In size ***M. acutidens*** occupies a position intermediate between the John Day species ***M. equiceps*** and ***M. praestans***. So far as it is possible to compare the dental measurements with those given by Marsh ‡ for *M. anceps* there is close agreement, but the skull of *M. acutidens* is not depressed between the orbits nor do the molars extend further behind the orbit than in *M. bairdi*, as is said to be true for *M. anceps*.

MEASUREMENTS.

Length of cranium from premaxillae to condyles inclusive	238mm
Length P^1-M^3 inclusive	85
Length M^1-M^3 inclusive	38.5
Length of diastema anterior to canine	10.5
Length of diastema posterior to canine	23
Length of canine from margin of alveolus to tip, measured on lingual aspect	17.5
M^1, antero-posterior diameter	13
M^1, transverse diameter*	16
M^2, antero-posterior diameter	13
M^2, transverse diameter*	16.3
M^3, antero-posterior diameter	12.5
M^3, transverse diameter *	16

University of California,
March, 1905.

---

‡ Marsh. Am. Jour. Sci., 3d Ser., Vol. VII, p. 250.

* Measured through the anterior cones at the widest part of the tooth crown.

EXPLANATION OF PLATE 14.

All figures three-fourths natural size, excepting Figs. 4 and 5, which are three times natural size.

Fig. 1.—*Allomeryx planiceps*, n. gen. and sp. Cranium from the left side.

Fig. 2.—*Allomeryx planiceps*, n. gen. and sp. Cranium from below.

Fig. 3.—*Hypertragulus*, sp. Right mandibular ramus. The dotted outlines are restored after Scott.

Fig. 4.—*Peromyscus parvus*, n. sp. Portion of maxillary containing first and second left superior molars. Occlusal view. ×3.

Fig. 5.—*Peromyscus parvus*, n. sp. Right mandibular ramus from above. ×3.

Fig. 6.—*Entoptychus sperryi*, n. sp. Cranium from above.

Fig. 7.—*Entoptychus sperryi*, n. sp. Cranium and mandible from the left side.

Fig. 8.—*Entoptychus rostratus*, n. sp. Cranium from below.

Fig. 9.—*Entoptychus rostratus*, n. sp. Cranium from the right side.

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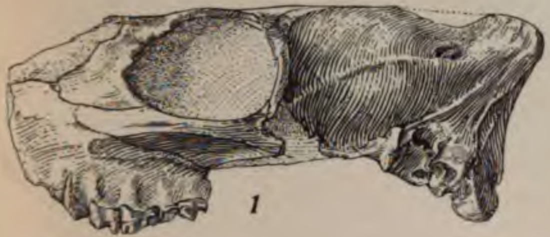
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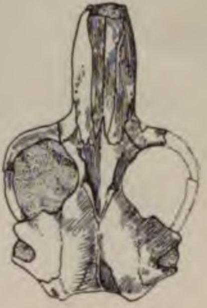
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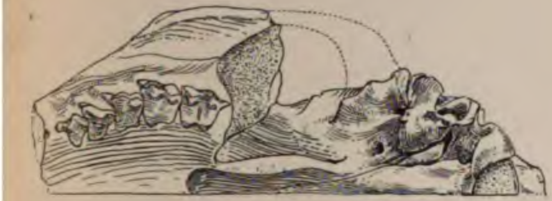
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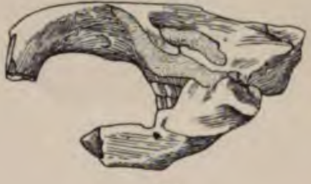
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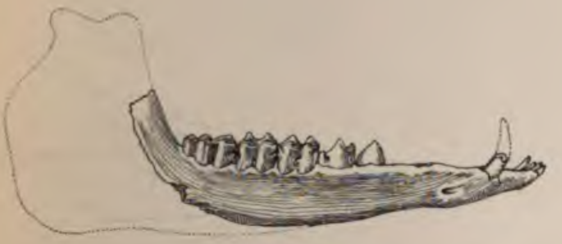
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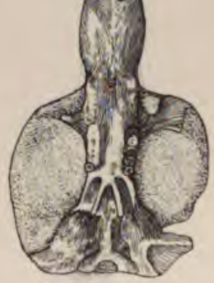
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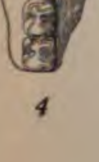
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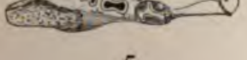
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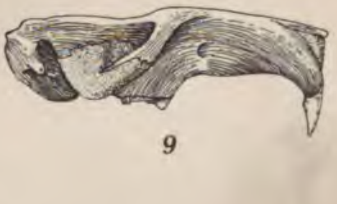
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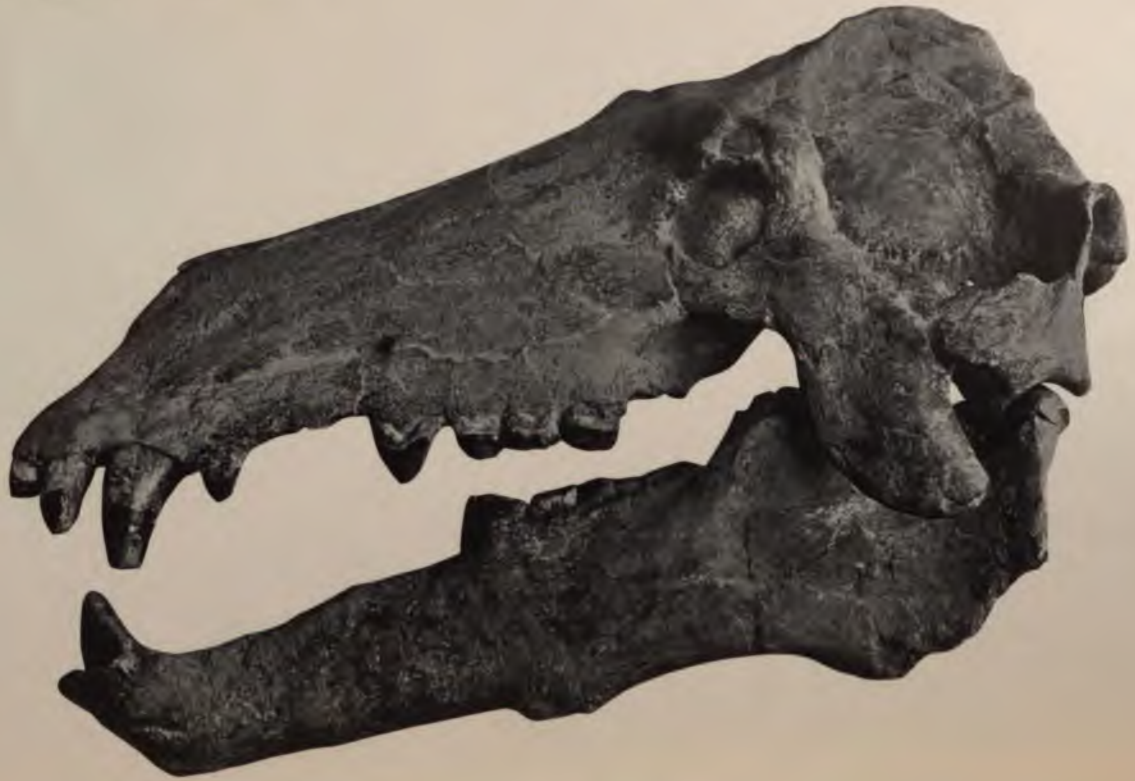
EXPLANATION OF PLATE 15.

Elotherium calkinsi, n. sp. Cranium and mandible from the left side. The extremity of the premaxillary supporting the upper incisors is restored in plaster. Figure about one-fourth natural size. ×.24.



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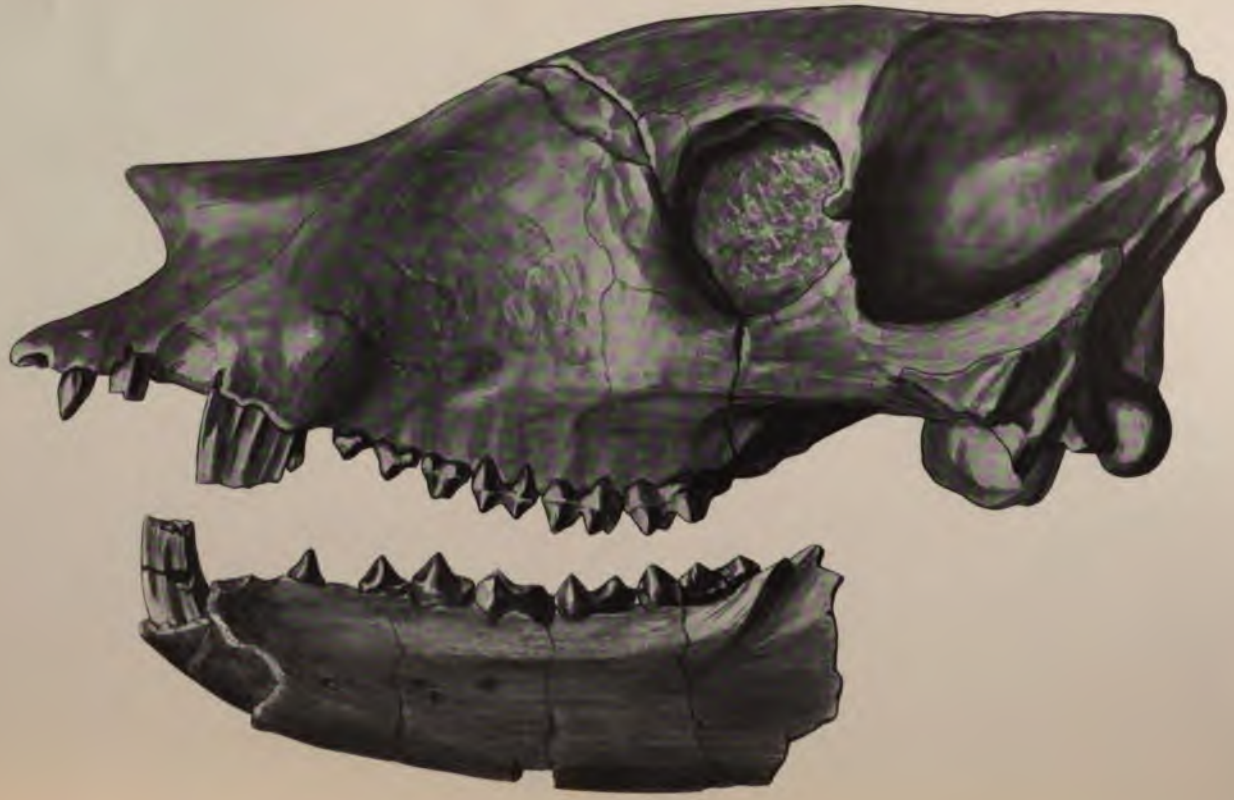
EXPLANATION OF PLATE 16.

Thinohyus (Bothrolabis) decedens Cope. Cranium and mandible from the left side. × ¾. Two specimens are combined in the drawing (Cranium No. $\overline{556}$ and mandible No. $\overline{1989}$). P^1 should not extend beneath the level of P^2. The anterior nasal region has been restored in the figure.



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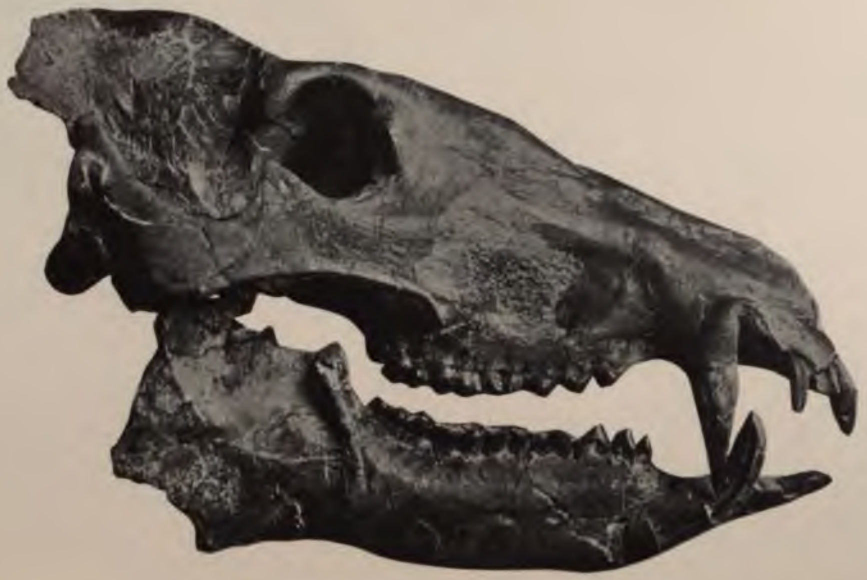
EXPLANATION OF PLATE 17.

***Thinohyus* (*Bothrolabis*) *osmonti*, n. sp.** Cranium and mandible from the right side. Figure somewhat less than one-half natural size. ×.460.



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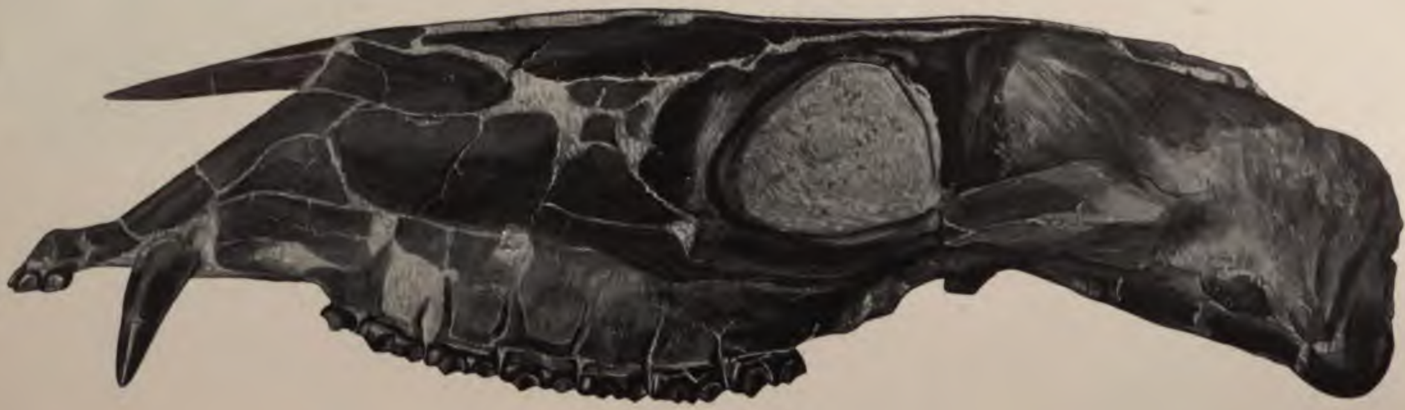
EXPLANATION OF PLATE 18.

Mesohippus acutidens, n. sp. Cranium from the left side. ×¾.



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UNIVERSITY OF CALIFORNIA PUBLICATIONS
BULLETIN OF THE DEPARTMENT OF
GEOLOGY
Vol. 4, No. 7, pp. 145-161, Pls. 19-23 ANDREW C. LAWSON, Editor

# NEW MAMMALIA
FROM THE
QUATERNARY CAVES OF CALIFORNIA

BY
WILLIAM J. SINCLAIR.

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INTRODUCTION.

The cave explorations conducted by the Department of Anthropology of the University of California have opened to the palaeontologist a new source of information regarding the Quaternary vertebrate fauna of this state. Occasional scattered teeth and bones from valley alluvium, clay beds, stream gravels and asphaltum deposits of Quaternary age occurring in various parts of California, have shown the presence of a considerable variety of mammalian species, but it has been impossible to group them into a fauna which might be regarded as a chronologic unit, owing to more or less variation in the age of these beds. The agencies involved in the accumulation of most of the bone-bearing deposits have proved destructive to all but the larger forms. On the contrary, the caves, having acted to a greater or less extent as receptacles for the accumulation of surface material, might be expected to afford a more complete faunal record, as the conditions governing preservation are usually quite favorable. This expectation has been fully realized.

A large number of the species of Quaternary mammals collected from the caves are new. The greater number of the new species were obtained from the Potter Creek Cave, the exploration of which has already been described.* New material was also secured from the well known Mercer's Cave situated near the town of Murphys in Calaveras County. In the description of the following species the writer is particularly indebted to Dr. C. H. Merriam for information concerning the relationships of the rodents.

THOMOMYS MICRODON, n. sp.

Pl. 19, Figs. 1-3.

Type.— No. 5738, Univ. of Cal. Palae. Coll. The anterior portion of a skull without the mandible.

Locality.—Potter Creek Cave, Shasta Co., California.

This species closely resembles *Thomomys mazama* Merriam C. H., from which it differs in having a very prominent ridge on the side of the rostrum, marking externally the position of the alveolus of the superior incisor. The fossa above the ridge is deep. *Thomomys niger* Merriam C. H. has the fossa behind the incisor ridge almost as deep as in the fossil form, but differs in having the rostrum heavier and the molars much larger. In the fossil form, the rostrum is rather shorter and broader than in *Thomomys mazama*, and the premaxillae are less pointed.

The new species belongs to the yellow toothed division of the genus. The incisors are flattened on the anterior side, the anterior outer corner is angular and the teeth are sharply decurved.

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*Science, N. S., Vol. XVII, No. 435, pp. 708-712, May 1, 1903; Univ. of Cal. Publ., Am. Arch. and Eth., Vol. 2, No. 1, 1904.

MEASUREMENTS.

Length of rostrum from base of P^4 to anterior surface of incisor	13.5mm
Length of rostrum from postero-inferior extremity of premaxillae to anterior surface of incisor	10.5
Greatest width of rostrum	7.5
Depth of rostrum from posterior extremity of nasals to margin of alveolus of P^4	11
Depth of rostrum from posterior extremity of nasals to postero-inferior extremity of premaxillae	9
Width across frontal between orbits	6.5
P^4, antero-posterior diameter	1.6
P^4, transverse diameter at widest part	1.5
M^1, antero-posterior diameter	1
M^1, transverse diameter	2
Width of incisor	2

APLODONTIA MAJOR FOSSILIS, n. sub-sp.

Pl. 19, Figs. 8 and 9.

Type.—No. 4160, Univ. of Cal. Palae. Coll. The right mandibular ramus, lacking the coronoid process and part of the angle.

Cotype.—No. 5265, Univ. of Cal. Palae. Coll. An imperfect cranium.

Locality.—Potter Creek Cave, Shasta Co., California.

Numerous lower jaws of an *Aplodontia* were found in all parts of the cave and at various depths beneath the surface of the cave deposit. The jaws all show the characters possessed by the type specimen. They differ from the typical *Aplodontia major* in having the dental foramen generally wider transversely. The ridge in front and below the masseteric fossa, in the fossil form, is usually continued across the lower side of the ramus and connected with the inner prominence of the angle, while in *A. major* a smooth space exists between the angle and the ridge in front of the masseteric fossa. In the fossil form the wall in front of the fossa above the angle, on the inner side of the ramus, is vertical for a longer distance below the opening of the alveolar canal than in the recent *major*. So far as it is possible to compare its dimensions with the measurements tabulated by Dr. C. H. Merriam,* the cranium agrees closely with *Aplodontia major*.

---

*Annals N. Y. Acad. of Sciences, Vol. III, No. 10, Table facing page 328.

MEASUREMENTS.

Least width of rostrum in front of zygomatic arches	17.25mm
Least interorbital width	10
Length of superior molar-premolar series (except P^3) measured on alveoli	17.3
Palatal width between alveoli of P^4	6.25
Palatal width between alveoli of M^3	6.5
Distance between alveoli of inferior incisor and P^4	13
Length of lower molar-premolar series measured on alveoli	18

TEONOMA SPELAEA, n. sp.

Pl. 19, Figs. 4-7.

Type.—No. 5362, Univ. of Cal. Palae. Coll. The anterior two-thirds of a skull of an adult individual, in which the teeth are not much reduced by wear.

Locality.—Potter Creek Cave, Shasta Co., California.

Teonoma cinerea is the form nearest to this new species, but the rostrum and incisive foramina are decidedly shorter in the fossil form than in *cinerea.* Also, the premaxillae extend farther back beyond the nasals, the nasals taper more posteriorly and the frontals have a greater interorbital width in the new species than in *T. cinerea.*

A large number of lower jaws were found in various parts of the cave. They differ from the typical *Teonoma cinerea* in having the enamel loops of the molars more evenly balanced on the two sides of the axis of the tooth row. In *cinerea* the loops are much longer on the inner side than on the outer side. In the cave specimens there is comparatively little difference. As but one species of *Teonoma* is represented in the Potter Creek Cave, the mandibles are also referred to *Teonoma spelaea.*

MEASUREMENTS.

Length of rostrum from base of P^4 to anterior surface of incisor	19	mm
Width of rostrum in front of infra-orbital foramina	9	
Depth of rostrum at middle of incisive foramina	9	
Length of incisive foramina	13	
Greatest width measured across both incisive foramina	3	
Width across frontal between orbits	6.5	
Length of superior molar-premolar series measured on alveolar borders	10.25	
M^1, antero-posterior diameter measured on alveolar border	4.3	
M^1, transverse diameter measured on alveolar border at widest part	2.3	
M^2, antero-posterior diameter measured on alveolar border	3	
M^2, transverse diameter measured on alveolar border at widest part	2.3	

PLATYGONUS (?), sp.

Text, Fig. 1.

Locality.—Potter Creek Cave, Shasta Co., California.

Three specimens from the Potter Creek Cave are doubtfully referred to this genus. Two of them are superior molars which are so poorly preserved and so badly worn that little can be determined regarding them. When first examined, they were thought to be referable to a large species of tapir and were so listed in the writer's preliminary paper.* The third specimen, a lower molar corresponding in size with the teeth of the superior series, is represented in text figure 1. The crown is divided into two transverse lobes by a deep valley which is unobstructed by ridges or tubercles. The notching of the anterior crest is slight, that of the posterior crest deep. A prominent extension of the cingulum posteriorly forms a heel which appears to have been more or less continuous around the external edge of the posterior lobe and to have joined a small tubercle at the outer margin of the transverse valley. This could not be well brought out in the figure as the enamel has been broken off, exposing the dentine. Anteriorly, there are traces of a narrow cingulum, but none exists internally. If the generic position of the specimen has been correctly determined, the remains indicate a species of *Platygonus* larger than any previously described.

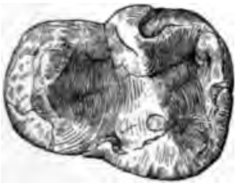

Fig. 1.

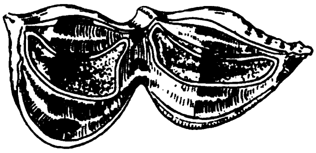

Fig. 2.

Fig. 1. *Platygonus*, sp. Potter Creek Cave.
Fig. 2. Camel tooth. Potter Creek Cave.

MEASUREMENTS.

Antero-posterior diameter of inferior molar	30 mm
Transverse diameter at widest part	23.5

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* Science, N.S., Vol. XVII, pp. 708-712, 1903.

CAMEL REMAINS.

Text, Fig. 2.

Although camels were abundant in California during the Quaternary, they did not play an important part in the fauna of the region about the Potter Creek Cave. Three molars of a camel were found in this cave but their fragmentary condition does not permit of a generic reference. One of them, a third inferior molar, is represented, natural size, in text figure 2. The heel has been gnawed off by rodents. Most of the cement and part of the external enamel layer have been removed by the same means.

EUCERATHERIUM COLLINUM Furlong and Sinclair.

Pl. 20, Figs. 1, 2.

Pub. Univ. Cal., Am. Arch. and Eth., Vol. 2, p. 18; Bull. Dept. Geol. Univ. Cal., Vol. 3, p. 412.

This ungulate is represented by abundant remains in the Potter Creek Cave, where it occurs in all bone-bearing strata. The specimens comprise numerous teeth from both jaws, loose podial elements, and broken horn-cores, some of which are supported by a part of the frontal. The various parts of the skeleton were not found associated, but there can be little doubt that they all belong to this genus. The horn-cores and the teeth of the superior series agree with the type specimen. As these remains do not indicate the presence of more than one species, the limb bones are also referred to *E. collinum.*

The various podial elements of *Euceratherium* agree closely in almost every particular with the corresponding bones in the feet of *Aplocerus,* excepting in size. Both anterior and posterior cannon-bones are short and robust. In the anterior cannon-bone, the posterior margins of the proximal articular surfaces lie in the same plane, while anteriorly they meet in an obtuse angle, producing an emargination of the anterior proximal border which is less marked than in *Aplocerus.* (Compare Pl. 20, figs. 2 and 3.) The nutrient foramen piercing the anterior surface of the bone above the distal condyles is also much smaller than in *Aplocerus.*

In the hind foot (Pl. 20, fig. 1) there is the same close agreement between the two genera. One of the most important differences is the close approximation anteriorly of the external trochlea and the condyle in the astragalus of *Euceratherium*. In *Aplocerus,* the two articular surfaces are separated by a wide groove.

The absence of close relationship between *Euceratherium* and the existing North American cavicorns is well brought out by a comparison of the foot structure, and especially of the cannon-bones. In *Ovibos* the cannon-bones are short and robust and agree, within a few millimeters, with the dimensions of the corresponding elements in *Euceratherium,* except in the length of the posterior cannon which is considerably greater in *Ovibos.** In the latter genus, the proximal facets of the anterior cannon-bone do not lie in the same plane posteriorly as in *Euceratherium.* Although there is close anatomical agreement with the feet of *Aplocerus,* the difference in size of the two genera is very great. The cannon-bones of the bighorn sheep are much larger in proportion to their width and are much less robust than in *Euceratherium.* In the domestic cattle, these bones are in some cases as robust as those of *Euceratherium* but are considerably longer. The extinct Bovinae of this Coast all have much broader and heavier cannon-bones.

It is apparent from these comparisons that no close relationship exists between *Euceratherium* and the goat-antelopes or the sheep. The cattle are excluded by fundamental differences in dental structure. The feet of *Ovibos* differ slightly in size and in minor anatomical peculiarities but the large horn-cores of that genus are of a different type from those of *Euceratherium.* No North American fossil forms are known from older formations which can be regarded as ancestral to the latter genus. It is possible that *Euceratherium* represents an Asiatic type which reached North America in the Quaternary along with the goat-antelopes, and that its ancestors are to be sought among the extinct forms of the Asiatic Pliocene.

---

* Dawkins, W. B. British Pleistocene Mammalia, Part V., Palaeont. Soc., 1872.

MEASUREMENTS.

Length of anterior cannon-bone measured on anterior surface	175 mm
Width of anterior cannon-bone measured at proximal end	56
Width of anterior cannon-bone measured across distal condyles	61
Thickness of anterior cannon-bone measured at middle of shaft	22
Length of posterior cannon-bone measured on anterior surface	180
Width of posterior cannon-bone measured at proximal end	49
Width of posterior cannon-bone measured across distal condyles	56.5
Thickness of posterior cannon-bone measured at middle of shaft	27
Greatest length of astragalus	62.5
Width of astragalus across proximal trochlea	37
Width of astragalus across distal condyles	42.5
Width of naviculo-cuboid	51.5
Greatest proximo-distal width of naviculo-cuboid at anterior border	18
Length of a phalanx of first row	58.5
Width of a phalanx of first row at proximal extremity	30.5
Width of a phalanx of first row at distal extremity	26
Length of a phalanx of second row	43.5
Width of a phalanx of second row at proximal extremity	29

APLOCERUS MONTANUS Ord.

Pl. 20, Figs. 3 and 4.

Parts of two anterior cannon-bones from the Potter Creek Cave are referred to this species. No. 4312 (Pl. 20, fig. 3) represents the proximal three-fourths of the right cannon-bone. The specimen shows traces of rodent grawing and is further disfigured by an exostitial growth at the proximal end, on the inner side of the bone. The middle of the shaft is slightly wider than the recent specimen of *Aplocerus* with which it is compared, but otherwise the two correspond closely in structure and dimensions. No. 4382 (Pl. 20, fig. 4), the distal half of a left anterior cannon-bone, is slightly larger than the corresponding element in *Aplocerus*, but in other respects does not differ from that genus. In the accompanying table, the dimensions of these two specimens and of *Aplocerus montanus* are given in parallel columns.

Cannon-bone	No. $\overline{4312}$	No. $\overline{4382}$	*A. montanus*
Width at proximal end	36 mm	....mm	35 mm
Width at middle of shaft	29	....	25
Greatest thickness at middle of shaft	13.5	....	13
Width across condyles	....	42.5	39.5
Width at nutrient foramen............	....	35.5	32
Greatest thickness at nutrient foramen....		15	14

NOTHROTHERIUM (?) SHASTENSE, n. sp.

Pl. 23, Figs. 1-5*a* and 8.

Type.—No. $\overline{8422}$, Univ. of Cal. Palae. Coll. An incomplete right mandibular ramus without teeth.

Locality.—Potter Creek Cave, Shasta Co., California.

This ground-sloth is represented in the cave collection by a large number of specimens. While teeth are wanting in the type, the peculiar shape and dimensions of the alveoli agree so closely with a number of molars from the same cave that there can be little doubt that they should be referred to the same species.

The type specimen lacks the greater part of the coronoid and angle. The anterior part of the symphysis is wanting, and the alveolar border is somewhat broken. The inferior border (Pl. 23, fig. 2) is strongly convex with the major convexity below the third lower molar. From this point it rises toward the symphysis, which is quite oblique instead of being almost vertical as in *Megalonyx jeffersonii*. The alveolar border in front of the second molar is somewhat broken and there is no trace of an alveolus for the first molar. The anterior opening of the alveolar canal is visible at the anterior extremity of the ramus. Its posterior opening is at the base of the coronoid process, on the outer side of the jaw.

The molar alveoli extend to the lower border of the ramus, from which they are separated by a thin shell of bone. All have parallel vertical walls, indicating that the specimen is of an adult individual.

In the second lower molar alveolus (Pl. 23, fig. 1) the lateral walls are inclined toward each other and if produced would meet anteriorly. The tooth occupying this alveolus was grooved on both lateral faces, dividing the column into two lobes of which the anterior was the smaller. Each lobe corresponds to a transverse ridge on the crown. The anterior wall of the alveolus is plane, while the posterior is slightly convex, with indications of a convex median rib.

The alveolus for the third molar is almost quadrangular in outline. The anterior wall is slightly concave, while the posterior is convex with a stronger convex rib situated about midway. The lateral walls meet the anterior face at a right angle. They are both grooved. A third lower molar of the left side, No. 8704 is represented on Plate 23, figures 4 and *4a*.

The fourth molar alveolus is cordate in cross-section, with the indentation on the outer side. The anterior lobe produced by this groove projects beyond the posterior. The tooth is represented in the cave collection by three specimens, Nos. 8485, 8328 and 8339, but none of them have the triturating surfaces preserved.

Fourteen molars referable to this species were collected from the cave, principally from stratum E. Three were found in stratum A and several in the Buried Gallery from stratum E or F. Some of these are shown on Plate 23, figures 3-*5a* and 8. Several are considerably curved and are doubtless of the superior series. They correspond in size to the lower molar alveoli. The last superior molar of the left side, No. 8497 is represented on Plate 23, figure 8. It is a triangular tooth with the posterior side plane, the anterior convex, and the outer plane and meeting the posterior at a right angle. The triturating surface of the crown has been injured by rodents.

MEASUREMENTS.

Length of inferior molar series measured on alveolar border	53.5mm
Greatest antero-posterior diameter of the alveolus of M_2	15
Greatest transverse diameter of the alveolus of M_2	17
Greatest antero-posterior diameter of the alveolus of M_3	15
Greatest transverse diameter of the alveolus of M_3	17
Greatest antero-posterior diameter of the alveolus of M_4	16
Greatest transverse diameter of the alveolus of M_4	17
Depth of ramus below alveolar border of M_3	50
Least distance between alveolar border behind M_4 and inferior border of jaw	43.5
Superior molar No. 8702, antero-posterior diameter at triturating surface	12
Superior molar No. 8702, transverse diameter at triturating surface	15.5

Third inferior molar No. 8704, antero-posterior diameter at triturating surface	12
Third inferior molar No. 8704, transverse diameter at triturating surface	15
Superior molar No. 8337, antero-posterior diameter at triturating surface	12.5
Superior molar No. 8337, transverse diameter at triturating surface	15

MEGALONYX SIERRENSIS, n. sp.

Pl. 20, Figs. 5-8; Pl. 21, Figs. 1 and 2; Pl. 22, Figs. 1-3.

Type.—A lower jaw, in the Harvard Museum of Comparative Zoology, Cambridge Mass., and No. 8130, Univ. of Cal. Palae. Coll. Left scapula, scapho-trapezius, trapezoid and magnum; right calcaneum and navicular; several imperfect metatarsals; a broken claw; part of the tibia; several vertebrae and numerous fragmentary bones. The Harvard specimen and the material at the University of California belong to the same individual.

Locality.—Mercer's cave, near the town of Murphys, Calaveras County, California.

A part of the remains of this sloth were found when Mercer's cave was first discovered. The mandible was presented to the Harvard Museum of Comparative Zoology in 1887 by Mr. Z. A. Willard. A broken tibia, a calcaneum and some other fragmentary bones lay on a block of limestone to which they were cemented by stalagmite, and were for years an object of curosity to persons visiting the cave. Through the kindness of Mrs. Mercer, these were presented to the University of California in 1901, and permission was obtained by Professor J. C. Merriam to search for additional material. At Professor Merriam's request, the writer visited the cave during the summer of 1902, securing several fairly complete bones, notably the scapula, a number of podial elements and a few vertebrae. The bones were found in the crevices between large limestone blocks in the narrow part of the cave above the chamber known as "The Flower Garden." Some were fairly well preserved, being coated with stalagmite, others were exceedingly soft and spongy, and a large amount of the material was too fragmentary to be of use.

The cave is developed along a fissure, running parallel with the strike of the Carboniferous limestone. Radiating from the present entrance there is an earth fan, but deeper down the fissure is almost choked by large fallen blocks. From the position of the sloth remains beneath some of these blocks it was evident that many of the latter had reached their present resting place at a later date than the bones. The abrupt descent precludes the idea that the animal wandered into the cave and there died. The best explanation of its presence seems to be that it was killed by a fall into the cave.

Through the kindness of Dr. C. R. Eastman, the specimen in the Harvard Museum was borrowed for examination. On the accompanying label it was stated that fragments of human crania were found associated with the mandible. Several human skeletons were found on the surface of the earth slope mentioned above, but these were probably comparatively recent Indian interments, while the sloth remains were from a much deeper part of the cave. Some of the human bones were incrusted with a very thin shell of stalagmite. It seems once to have been the custom of the Indians in this region to cast the bodies of the dead into such natural pits and caves as the region afforded. The human remains in Mercer's cave were apparently introduced in this way.

The ground-sloth bones collected are those of a young animal and differ in several respects from *Megalonyx jeffersonii* with which some of the dimensions compare favorably.

Two views of the *mandible* are given on Plate 21. The jaw is smaller than the corresponding element in *Megalonyx jeffersonii,* but this is due in part to the youth of the animal, in which the epiphytic elements were still distinct. The bone is invested with a layer of stalagmite which increases its size slightly. The second and fourth molars on the right side have the triturating surfaces broken. Some of the teeth are more or less coated with stalagmite. The canine molars are not much curved. The external dentine layer only could be distinguished. The internal convex rib is not quite central, and the concavity bounding it posteriorly is deeper than the anterior one.

A comparison of the dimensions tabulated on page 159 with the measurements of the mandible of *Megalonyx jeffersonii* given by Leidy,* shows that while the jaw is shorter and shallower, the posterior molars are of the same size as in that species.

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* J. Leidy, A memoir on the Extinct Sloth Tribe of North America Smithsonian Contrib., Vol. VII.

The *scapula* (Pl. 22, fig. 1) is broken anteriorly, and lacks the supraspinous fossa, the scapular spine, and the coracoid process. These parts had disappeared before the specimen was discovered. At the anterior border of the glenoid fossa there is a rough surface for the attachment of a glenoid epiphysis like that found in young individuals of *Megalonyx jeffersonii.*

The glenoid fossa as preserved in the cave specimen is much longer and wider than in *jeffersonii.*

The anterior extremity of the superior border of that part of the scapula preserved is greatly thickened; the posterior extremity much less so. The posterior scapular border is strongly concave antero-posteriorly, differing in this respect from *jeffersonii.*[*]

The subscapular fossa, so far as preserved, is smooth and basin shaped, without the alternation of ridges and sloping surfaces described by Leidy for *jeffersonii.*[†]

The supraspinous fossa is not shown, and the thickening of the anterior border mentioned above represents the base of the scapular spine. The infraspinous fossa is convex in all directions, with a low median ridge. In *jeffersonii* both fossae on the lateral surface of the scapula are deeply concave.[‡]

No foramina are indicated beneath the thin layer of stalagmite which preserves the specimen.

The *scapho-trapezius* (Pl. 20, figs. 7-8, *s-t*) is irregularly tetrahedral in shape, with a broad convex proximal facet for the radius. Distally, the most prominent facet is that for the trapezoid, which extends from the dorsal almost to the palmar margin of the bone, while in *jeffersonii* it is broadly separated from the latter. The facets for the magnum and lunar are not well preserved, as the specimen has suffered considerably from decay which has reduced its dimensions at several places. A similar though slightly larger and somewhat less complete bone was obtained from the Potter Creek Cave (No. 8201).

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[*] J. Leidy, *op. cit.* Pl. VIII, fig. 3.
[†] *Ibid.* pp. 24 and 25.
[‡] *Ibid.* p. 25.

The trapezoid (Pl. 20, figs. 7-8 *t*) is a small element, triangular in section when viewed from below. The facet for articulation with the scapho-trapezius which occupies the entire proximal surface is convex in dorso-palmar section and sigmoid transversely. The articulation is continued on the inner side of the bone as a surface inseparable from the proximal one. An oblong dorsal facet, concave in dorso-palmar section and a small ellipsoidal convex palmar facet, separated from the former by a groove, articulate with the magnum. A large distal facet, sigmoid in dorso-palmar section, articulates with the second metacarpal.

The *magnum* (Pl. 20, figs. 7-8 *m*) is broken, and has lost the articular surfaces for the scapho-trapezius and the lunar. There is an irregularly oval palmar facet for the scapho-trapezius, a concave roughly quadrilateral distal facet for the third metacarpal and two facets for the unciforme, a large irregularly elongate facet proximally, and a small acutely ovoidal facet on the anterior distal edge of the bone.

The *calcaneum* (Pl. 22, figs. 2 and 3) differs from the corresponding element in *Megalonyx jeffersonii* in the following respects:

(a) The postero-inferior extremity of the tuber calcis is directed toward the inner side, while in *jeffersonii* it is directed toward the outer side.[*]

(b) The inner surface of the tuber calcis is concave antero-posteriorly, while in the vertical direction it is convex below and plane or slightly concave above. In *jeffersonii*, it is concave in both directions.

(c) In *jeffersonii*, "posterior to the articular extremity, the calcaneum forms a large plate nine inches in depth, and only a fourth of an inch in thickness toward the center."[†] In the Californian species, this plate exceeds three-quarters of an inch in thickness toward the center and is never less than half an inch in thickness at the margin.

(d) While the neck of the tuber, behind the articular surfaces is only slightly wider vertically, than in *jeffersonii*, the length of the calcaneum and the width across the fan-like expansion at the posterior extremity of the bone is far less.

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[*] J. Leidy, *op. cit.*, Pl. XII, fig. 6.

[†] *Loc. cit.* p. 41.

The *navicular* (Pl. 20, figs. 5-6) has a shape slightly different from that in *jeffersonii,* being irregularly triangular in outline, with the angles broadly rounded. On the distal surface, the facets for the cuneiform bones are separated posteriorly by a sharp ridge, while in Leidy's figure[*] of the navicular of *jeffersonii* they are represented as separated by a groove.

Two *vertebrae* are preserved, a caudal and an anterior dorsal. In the caudal, the vertebral canal is low and broad and the transverse processes, arising from the centrum are directed posteriorly. The epiphyses are wanting and the sub-epiphytic margins are bent inward toward the median plane of the centrum. In the dorsal, the transverse processes are broad and are situated high up on the neural arch, rising above the zygapophyses. The spine is short with acute anterior edge. The neural canal is circular. The centrum is not preserved. Below the prezygapophyses, a small, hemispherical process rises from the anterior surface of the neural arch.

Fragments of several other bones were found, but they are all too incomplete to describe.

The species is separated from the Californian forms of the same genus described in the present paper by the size of the teeth and the shape of the jaw, in which respect it resembles *Megalonyx jeffersonii*, differing from that species, however, in many skeletal particulars. It has not been identified from the Potter Creek Cave, unless the doubtfully determined specimen referred to *Megalonyx jeffersonni* can be shown to belong here.

The specific name refers to the locality, in the foot hills of the Sierra Nevada Range.

MEASUREMENTS.

Length of ramus from anterior extremity of symphysis to condyle inclusive	261.5 mm
Length of lower molar series (M_2-M_4)	63
Length of symphysis externally	81
Depth of jaw below M_2	75
Depth of jaw below M_4	70

Diameters of lower molar crowns not including stalagmite:

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[*] J. Leidy, *loc. cit.* Pl. XIII, fig. 8.

M_1, antero-posterior diameter of grinding face	28 mm
M_1, transverse diameter of grinding face	12
M_2, antero-posterior diameter	17
M_2, transverse diameter	20
M_3, antero-posterior diameter	16
M_3, transverse diameter	23
M_4, antero-posterior diameter	17
M_4, transverse diameter	23.5
Greatest length from glenoid cavity of scapula to superior scapular border	295
Distance from glenoid border to posterior inferior angle of scapula	136
Greatest width of glenoid cavity of scapula	102
Greatest length of glenoid cavity of scapula	100
Greatest length of calcaneum	142
Greatest width of fan-like expansion of tuber calcis	131
Width of neck of tuber calcis at narrowest point	67
Greatest width of posterior margin of tuber calcis	39
Least width of posterior margin of tuber calcis	13
Distance from posterior extremity of tuber to inferior border of astragalar facet	106
Greatest dorso-plantar diameter of navicular	70
Greatest transverse diameter of navicular	64

MEGALONYX (?), sp.

Pl. 23, Fig. 6.

Locality.—Potter Creek Cave.

The large molar shown on plate 23, figure 6 (No. 8705) is doubtfully referred to *Megalonyx.* It is oblong in outline, with one of the narrow lateral faces convex and the other with a median groove. The remaining faces are respectively broadly concave, and convex with a low median convex rib. At either extremity of the deep groove crossing the triturating surface there are shallow concavities separated from each other by a convex surface. In this respect, and in the shape of the crown and its superior size, the tooth is unlike that of any species of *Megalonyx* known from this state. In shape the tooth is also unlike *Mylodon.* It is broken off a short distance below the triturating surface.

MEASUREMENTS.

Antero-posterior diameter of molar at widest part	16 mm
Transverse diameter of molar	27.5

MEGALONYX WHEATLEYI Cope (?).

Pl. 23, Fig. 7.

Locality.—Potter Creek Cave.

A single specimen (No. 8203) is referred to this species. It has the characteristic triangular form of the superior molars of *Megalonyx*, with the apex of the triangle rounded and the base slightly grooved. The remaining faces are respectively plane and convex. In dimensions, it agrees with Cope's *Megalonyx wheatleyi*, and in the absence of negative characters has been referred to that species. *Megalonyx wheatleyi* was described from material collected from the ossiferous deposit filling a fissure exposed in a quarry at Port Kennedy, Pennsylvania. The posterior molars can be distinguished from those of *Megalonyx jeffersonii* only by their inferior size. The tooth from the Potter Creek Cave is intermediate in this respect between *Nothrotherium shastense* and *M. sierrensis.* It is slightly wider at the base of the pulp canal than at the triturating surface, indicating that the animal was not fully mature.

MEASUREMENTS.

Antero-posterior diameter of molar at triturating surface....	12
Antero-posterior diameter of molar at margin of pulp canal...	12.5
Transverse diameter of molar at triturating surface..........	19.5
Transverse diameter of molar at margin of pulp canal........	20.5

MEGALONYX JEFFERSONII Leidy (?).

Locality.—Potter Creek Cave.

This identification is based on a fragmentary canine-molar (No. 8620) which agrees in dimensions with *Megalonyx jeffersonii.* Although not much curved, the obliquity of a small part of the triturating surface preserved indicates that the tooth probably belongs to the superior series. The convex rib is situated midway on the inner side of the tooth with a well marked concavity on either side. It is possible that this tooth should be referred to *Megalonyx sierrensis,* in which the upper molars are not known, but the convex rib in the lower canine-molars of that species is less centrally located than in the specimen in question. If the tooth were entire, the measurements given below would be slightly increased. In particular, the antero-posterior diameter would be lengthened one or two millimeters.

MEASUREMENTS.

Antero-posterior diameter of canine-molar.....................	34mm
Transverse diameter of canine-molar	16

EXPLANATION OF PLATE 19.

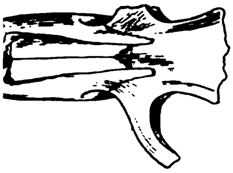
Figures 1-7 *are reproduced one and one-half times natural size; figures* 8-11 *are reproduced natural size.*

Figs. 1-3. *Thomomys microdon* n. sp. Superior, inferior and lateral views of the type specimen.

Figs. 4-6. *Teonoma spelaea*, n. sp. Superior, lateral, and inferior views of the type specimen.

Fig. 7. *Teonoma spelaea.* Superior view of the mandible.

Figs. 8, 9. *Aplodontia major fossilis*, n. sub-sp. External and internal views of the right ramus of the mandible.



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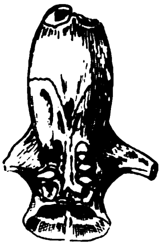

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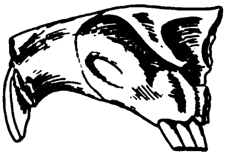

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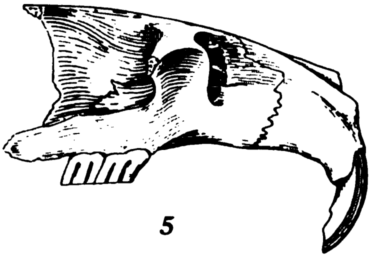

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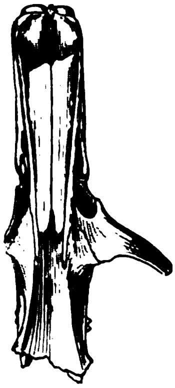

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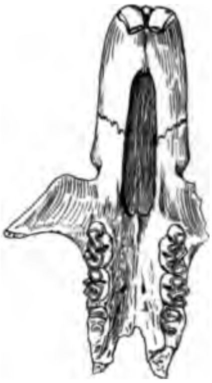

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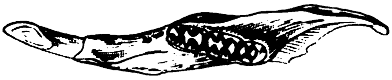

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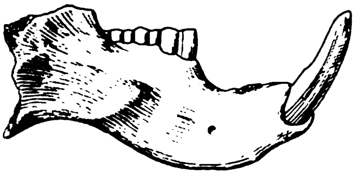

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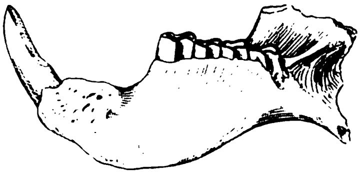

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EXPLANATION OF PLATE 20.

All figures are reproduced one-half natural size.

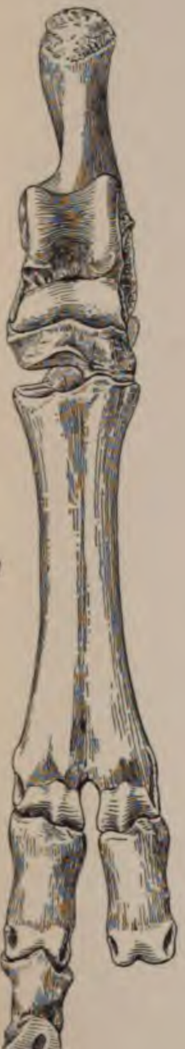
Fig. 1. *Euceratherium collinum.* Left pes. Several dissociated elements are combined in the drawing.

Fig. 2. *Euceratherium collinum.* Left anterior cannon-bone.

Figs. 3, 4. *Aplocerus montanus.* Portions of anterior cannon-bones. The proximal three-fourths of the right cannon-bone is represented in figure 3, while 4 shows the distal half of the same element of the opposite side.

Figs. 5, 6. *Megalonyx sierrensis*, n. sp. Views of the proximal and distal surfaces, respectively, of the right navicular.

Figs. 7, 8. *M. sierrensis.* Views of the dorsal and distal aspects of the left scapho-trapezius (*s-t*), trapezoid (*t*), and magnum (*m*). One of the facets for articulation between the scapho-trapezius and lunar is seen at (1).



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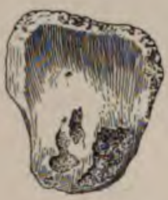

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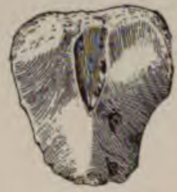

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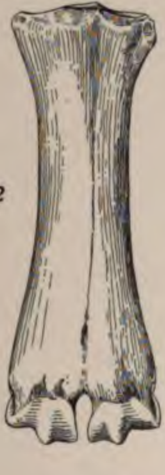

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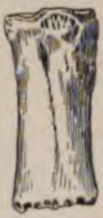

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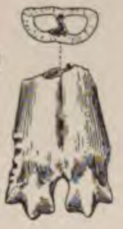

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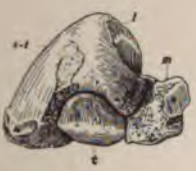

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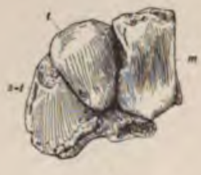

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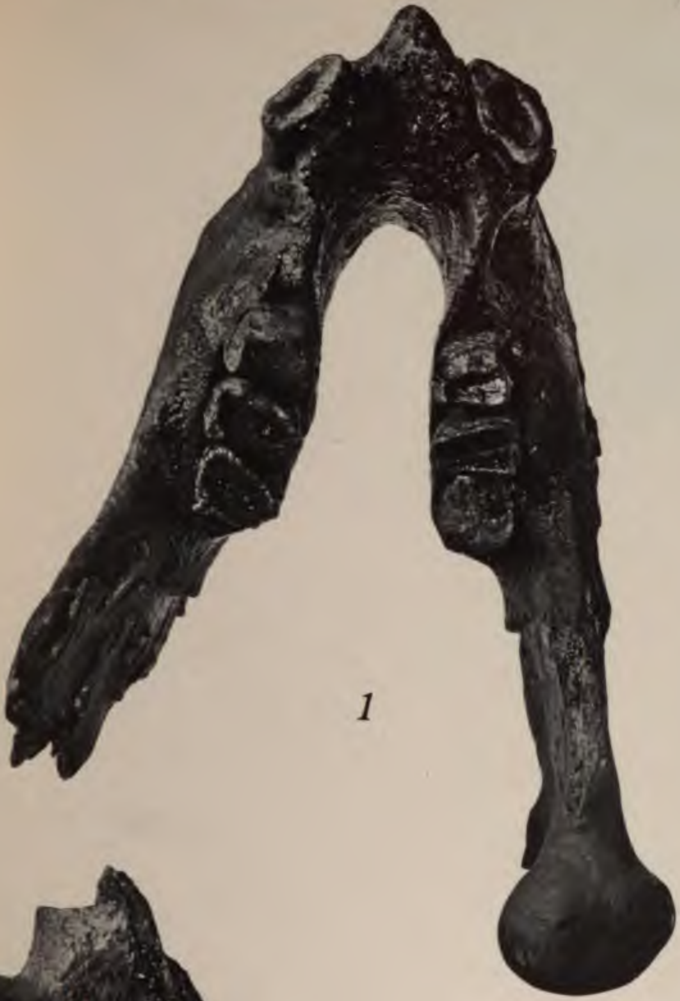
EXPLANATION OF PLATE 21.

Both figures are somewhat more than one-half natural size (*i.e.* ×.62).

Figs. 1, 2. *Megalonyx sierrensis*, n. sp. Superior and lateral aspect of the mandible. Reproduced from photographs of the specimen in the Harvard Museum of Comparative Zoology.



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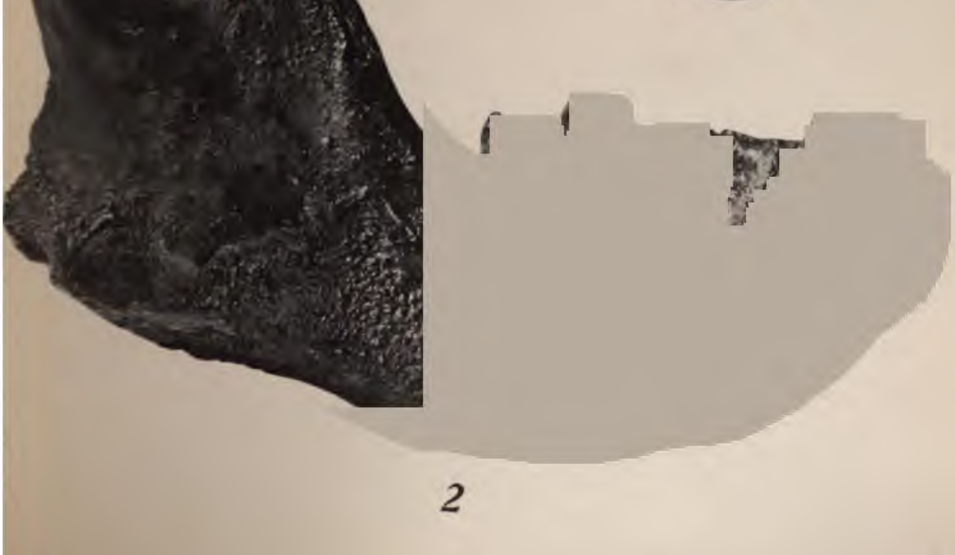

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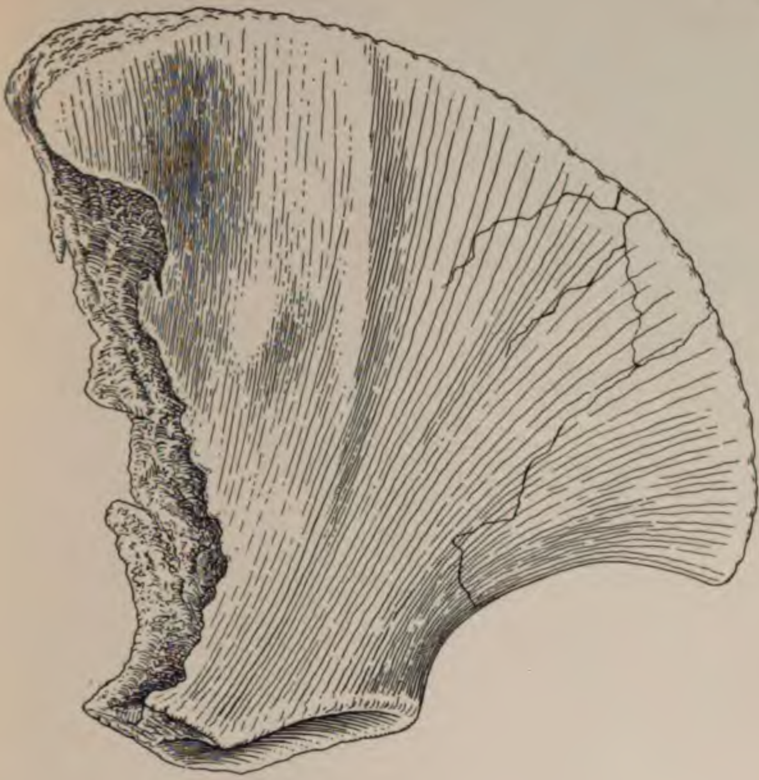
EXPLANATION OF PLATE 22.

All figures are reproduced one-half natural size.

Fig. 1. *Megalonyx sierrensis*, n. sp. Left scapula, external view. The supraspinous portion has been broken away.

Fig. 2. Articular surface of the right calcaneum.

Fig. 3. Inner side of the right calcaneum.



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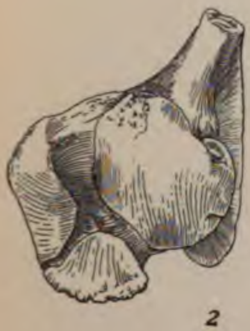

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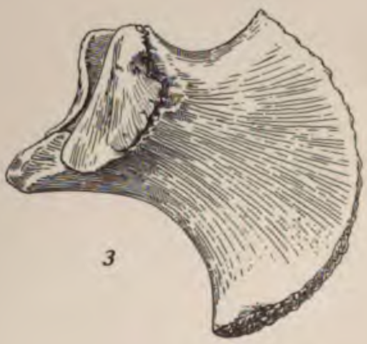

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EXPLANATION OF PLATE 23.

All figures are reproduced natural size.

Figs. 1, 2. *Nothrotherium* (?) *shastense*, n. sp. Right ramus of the mandible viewed from above and from the inner side.

Figs. 3, 3*a*. *N.* (?) *shastense*. A superior molar of the same crown and lateral views, showing the curvature of the tooth and the pattern of the triturating surface.

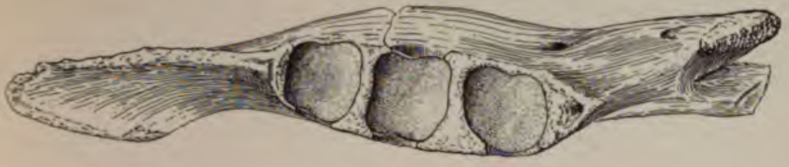
Figs. 4, 4*a*. *N.* (?) *shastense*. Left third inferior molar, showing the pattern of the triturating surface and the concave anterior wall of the tooth.

Figs. 5, 5*a*. *N.* (?) *shastense*. Superior molar No. 8337, referred to the same species as the above, showing the triturating surface and the convex rib on the side of the tooth crown.

Fig. 6. *Megalonyx* (?). View of the triturating surface of a molar (No. 8705, doubtfully referred to this genus.

Fig. 7. *Megalonyx wheatleyi* (?). Crown view of amolar. The triturating surface is slightly broken.

Fig. 8. *Nothrotherium shastense*. Triturating surface of the fifth superior molar of the left side. The tooth has been damaged by rodent gnawing and its outline is restored by a broken line. The restoration is based on the shape of the tooth shown at the margin of the pulp canal.



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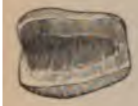

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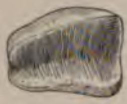

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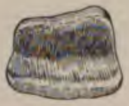

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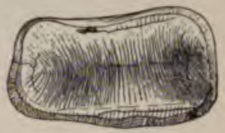

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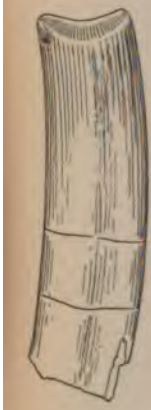

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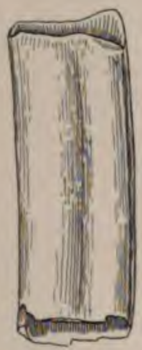

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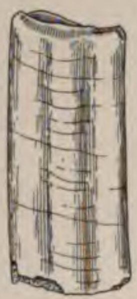

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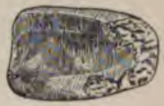

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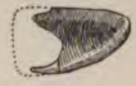

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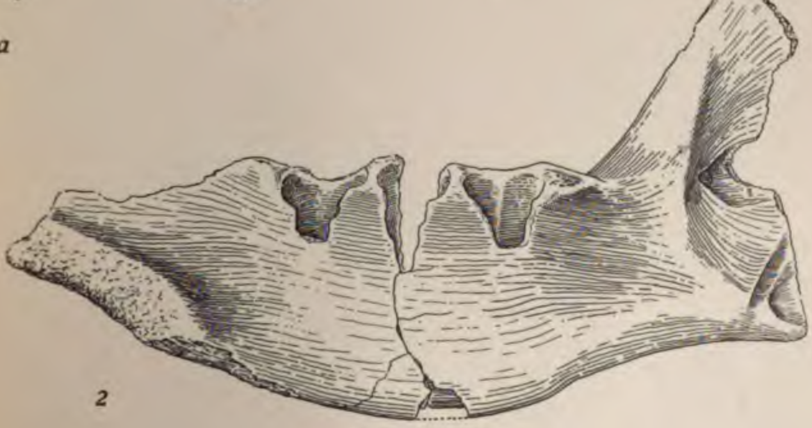

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Vol. 4, No. 8, pp. 163-169, Pls. 24-25 ANDREW C. LAWSON, Editor

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# PREPTOCERAS, A NEW UNGULATE
FROM THE
SAMWEL CAVE, CALIFORNIA

BY

EUSTACE L. FURLONG

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INTRODUCTION.

In the course of the exploration of the Quaternary Caves of Shasta County, conducted by the Department of Anthropology of the University of California during the past three summers, a large quantity of ungulate material has been brought together Through the kindness of Professor J. C. Merriam, it has been the writer's privilege to prepare and study this collection.

In the material from the Samwel Cave there is a nearly complete skeleton of a large sheep-like animal differing from all described forms. There are also the skull and horns of another individual of the same species, and other more fragmentary material. These animals were contemporary with *Euceratherium collinum** recently described from Potter Creek Cave; the remains of the two being found associated in the Quaternary deposits of Samwel Cave.

---

* Univ. of Cal. Bull. Dept. Geo., Vol. 3, No. 20, pp. 411-415, Pls. 50-51.

While resembling *Euceratherium* in general, the cranium and horns are markedly different in many respects. These differences seem to warrant the placing of the new type in a distinct genus for which the name *Preptoceras* is proposed.

PREPTOCERAS SINCLAIRI, new genus and species.[*]

Pls. 24 and 25.

Type.—Specimen No. $\overline{8896}$, Univ. of Cal. Palaeont. Coll.

Generic characters.—Horn-cores solid, on the posterior extremity of the frontals, well back of the orbits and rather widely separated. Frontals rising at a steep angle from nasals to form a greatly swollen area between and high above the orbits. Lachrymal pit broad and shallow. Teeth hypsodont, large, without cement, superior molars with very small median accessory style on the inner sides. Horn-cores with distinct burrs at the base.

Specific characters.—Proximal third of horn-cores flattened anteriorly. Proximal third directed outward and slightly upward, distal third curving forward and downward with an elevated point. Occiput with no median keel above foramen magnum.

Occurrence.—The type specimen was discovered by the writer in Samwel Cave on the McCloud River, Shasta County, California. It consists of the greater part of the skeleton of a young individual. The skull lacks the median portion. This region is, however, represented in another individual. The superior dentition is complete on the left side. The left ramus of the mandible was in articulation with the skull, as were also the cervical vertebrae.

The remains were excavated from a shallow deposit in the deepest chamber of the cave, at a depth of six inches to two feet. The bones were more or less covered by stalagmite varying in thickness from one to twenty-five millimeters. A large quantity of material from the same deposit is referable to this genus and to *Euceratherium.*

[†] I take pleasure in naming this species in honor of Dr. Wm. J. Sinclair, who was identified with the first extensive cave exploration in California.

From the associated fauna and the occurrence of the deposit, *Preptoceras* is considered to be of Quaternary age, but probably somewhat later than the epoch represented by the principal deposit at Potter Creek Cave.

Cranium.—The cranium is that of an immature individual in which the last permanent teeth are being erupted. It is slightly larger and more robust than the skull of *Euceratherium*. Viewed from the front there is a strong resemblance to *Budorcas taxicola,* and like the latter there is a suggestion of affinity with the Musk Ox. The horn-cores of *Preptoceras* differ from those of *Budorcas* and *Ovibos* in length and curvature. In both of these characters they closely resemble those of *Bos*.

The nasals and frontals are partly destroyed in the type specimen, but in another individual from the same deposit they are complete. The nasals are flat dorsally with steeply sloping sides. The anterior ends are decurved and converge to form a blunt point. Posteriorly, the ends slope upward to the fronto-nasal suture. The posterior ends are not separated to form two distinct points as in *Budorcas*.

The frontals rise from the nasals at a steep angle and are much inflated dorso-ventrally above the orbits. In *Euceratherium* the frontals, while slightly convex above the orbits, do not rise from the nasals at a sharp angle, but present rather a plane with uniform inclination from the nasals to the base of the horns.

The horn-cores grow from the extreme posterior and lateral ends of the frontals, and show distinct burrs at the base. They are situated rather wide apart at the base. The cancellous tissue extends but a short distance above the burrs. In the proximal two-thirds the anterior surface is flattened, and the posterior surface strongly convex. The distal third is rounded and tapers gradually. In *Euceratherium* the horn-cores are much closer together at the base, and in size and curvature suggest those of *Capra*.

The parietals and frontals are fused just back of the horns, the parietals forming the dorso-posterior roof of the cranium. The parietals slope posteriorly at a sharp angle to the prominent lambdoidal crest.

In *Preptoceras* the occipital suture is midway between the lambdoidal crest and the foramen magnum, while in *Euceratherium* the suture is much nearer the crest and gives a relatively greater area to the occipital than in *Preptoceras*. The lambdoidal crest overhangs the occiput, forming deep fossae on either side of the median tubercle. These are absent in *Euceratherium*. In the latter, above the mastoid, where the squamosal, occipital and parietal elements meet, prominent tubercles are formed, from which a buttress-like ridge passes dorsally to the base of the horns. This brings the parietals almost into the plane of the occiput and gives the back of the cranium a square appearance. This angulation is absent in *Preptoceras*. There is no ridge from the lambdoidal crest to the base of the horns and the parietals pass back of the horn-cores to the cranial roof in a uniformly curved surface, making a deep concavity between the crest and the horn-cores.

The elements of the basioccipital region are in general broader than in *Euceratherium*, though the foramina occupy the same positions. The occipital tubercles have not such well defined anterior and posterior areas, the median constriction being less marked in *Preptoceras*. The paroccipital processes are relatively more robust and higher. A raised posterior elongation of the low-lying tympanic bullae rests against its base more distinctly than in *Euceratherium*.

The maxillae are greatly swollen at the sides as in *Euceratherium*. This is apparently not due entirely to the immaturity of the individual. The palatal portion of the maxillae differs in the relative measurements. The anterior margin of the posterior nares is between the crescents of the last superior molars, while in *Euceratherium* the margin is on a plane with the posterior border of the last molars. The shallow fossae on either side below the narial border in *Euceratherium* are absent in *Preptoceras*, this region being more like that in *Aplocerus*.

Dentition.—The dentition resembles even more closely that of *Ovibos* than does *Euceratherium*, the length of the dental series being the same, as that of an adult skull of *Ovibos* in the University collection.

The superior dental series on the left side is nearly complete, with the last deciduous molar about to give place to the permanent tooth, thus making the individual probably two years old. The crowns of the teeth are unworn and present in general the form seen in the *Ovinae*. They are hypsodont with no cement. In the deep groove at the confluence of the walls of the inner crescents of the molars there is a very small accessory style which is not present in *Euceratherium*. The inferior promolars of the left side are missing, but those in the right ramus are present. P_3 is about to be shed, the permanent teeth just appearing above the alveolar border. The second milk incisors are present and the crowns of the permanent incisors visible. Their form is much like those of *Ovibos*.

Vertebrae.—The number of cervical and lumbar vertebrae corresponds to that in the *Ovinae*. Their centra are not so sharply keeled ventrally as in *Capra* and *Aplocerus*. They are relatively shorter than in these latter genera and are much heavier and robust in every way. The pre- and post-zygapophyses of the cervicals are more like those in the domestic goat than *Aplocerus*, in that there is no sharp lateral constriction separating them into distinct anterior and posterior limbs, but they form an antero-posterior lamella. The lumbar and sacral vertebrae closely resemble those of *Aplocerus*. No caudal or thoracic vertebrae were present and they have been restored, the former from *Aplocerus*, the latter from vertebrae associated with *Preptoceras* remains in Samwel Cave.

Limbs and Girdles.—The scapula in *Preptoceras* is rather heavy compared with that in *Aplocerus*. The acromion is not produced in a convex anterior surface in its distal half as in *Aplocerus*.

The humerus is robust, it has a very broad head and strongly developed tuberosities with a deep bicipital groove. The shaft is heavy with prominent deltoid and supinator ridges.

The radius, ulna and distal elements of the fore limb are in general like those in the *Ovinae*, though heavier. The articular facets of the carpalia are placed so as to throw the knee toward the median line, resembling *Bos* in this respect in a greater degree than the *Ovinae*.

The pelvis is heavy and narrow, indicating an individual of the male sex. Though no pelvis of *Euceratherium* has been identified, the type specimen is judged to be of male sex. Portions of the skulls of eight individuals in the collection are referable to *Euceratherium* and the differences noted in them indicate difference of sex. The elements of the hind limbs, like those of the fore limbs, are heavy and rugged compared with the typical *Ovinae*. The greater and lesser trochanter, gluteal tubercle and all processes for muscular attachment are strongly developed.

Affinities.—Preptoceras has interesting resemblances to *Budorcas* and to *Ovibos*, though not nearly related to either. It probably bears somewhat the same degree of relation to *Ovibos* that *Budorcas* does. Its closest affinity is with its contemporary *Euceratherium*. It stands in about the same relation to the *Ovinae* as does the latter and is tentatively placed in that subfamily. *Preptoceras* and *Euceratherium* have unique characteristics in common and will probably have to be placed in a group by themselves when studied further.

Measurements.

Basilar length of cranium from the anterior border of the alveolus of P^2 to condyle, inclusive	300 mm
Greatest length of frontal from fronto-nasal suture to occiput, approximate	143
Width between superior orbital rims	160
Width across bases of horn-cores	144
Width of palate at M^3	89
Greatest extent of molar arches measured between inferior borders	180.5
Depth of molar arch below orbit	48
Antero-posterior diameter of horn-core at base	96
Transverse diameter of horn-core at base	77
Length of superior dental series on alveolar border	139.7
Antero-posterior diameter across head of humerus	114
Length of humerus	300
Length of radius	305
Length of scapula	305
Length of a metacarpal	180
Length of 1st phalanx of fore foot	65.5
Length of 2nd phalanx of fore foot	37.5
Length of a hoof of fore foot	58

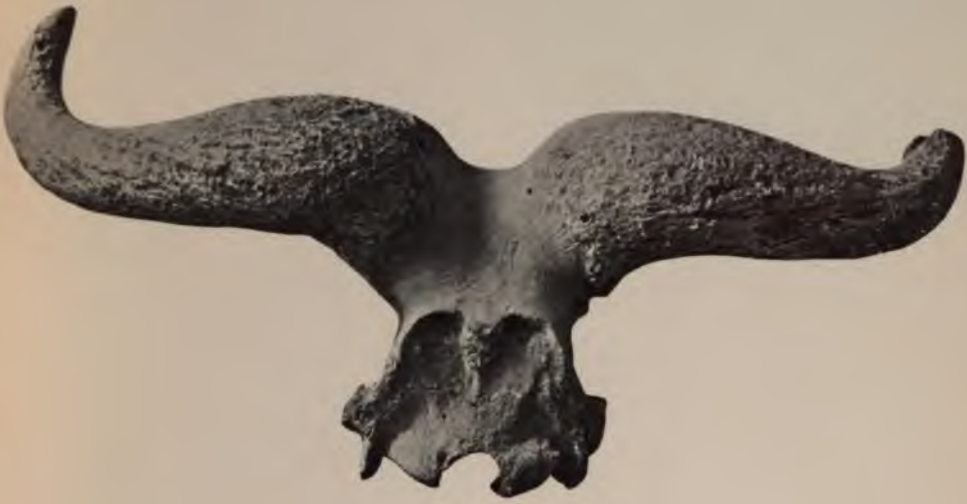
Length of pelvis	375
Length of femur	350
Length of tibia	360
Length of a metatarsal	190
Length of 1st phalanx of hind foot	64
Length of 2nd phalanx of hind foot	38
Length of a hoof of hind foot	58

University of California,
May, 1905.

EXPLANATION OF PLATE 24.

Fig. 1. *Preptoceras sinclairi.* Posterior aspect of cranium and horn-cores ×.22. Type specimen, No. $\overline{8896}$.

Fig. 2. *Preptoceras sinclairi*, n. gen. and sp. Lateral view of cranium, ×.3. Specimen No. $\overline{1559}$.



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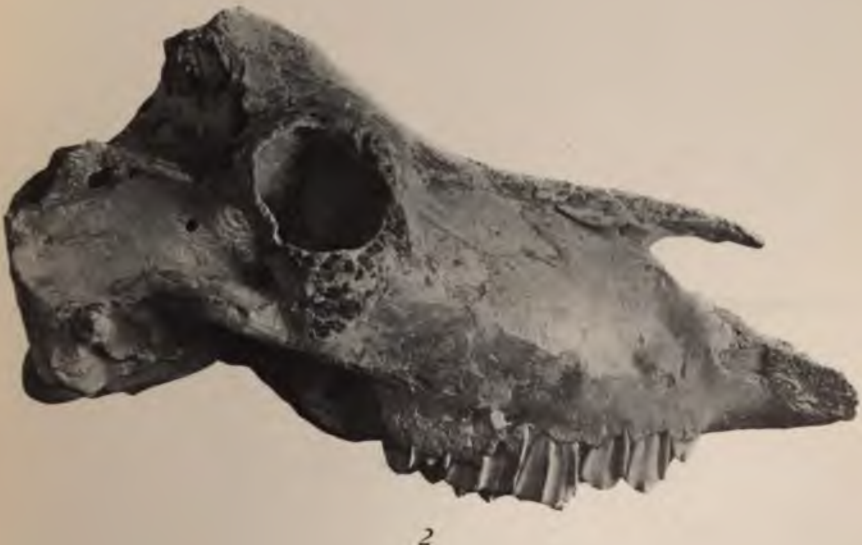

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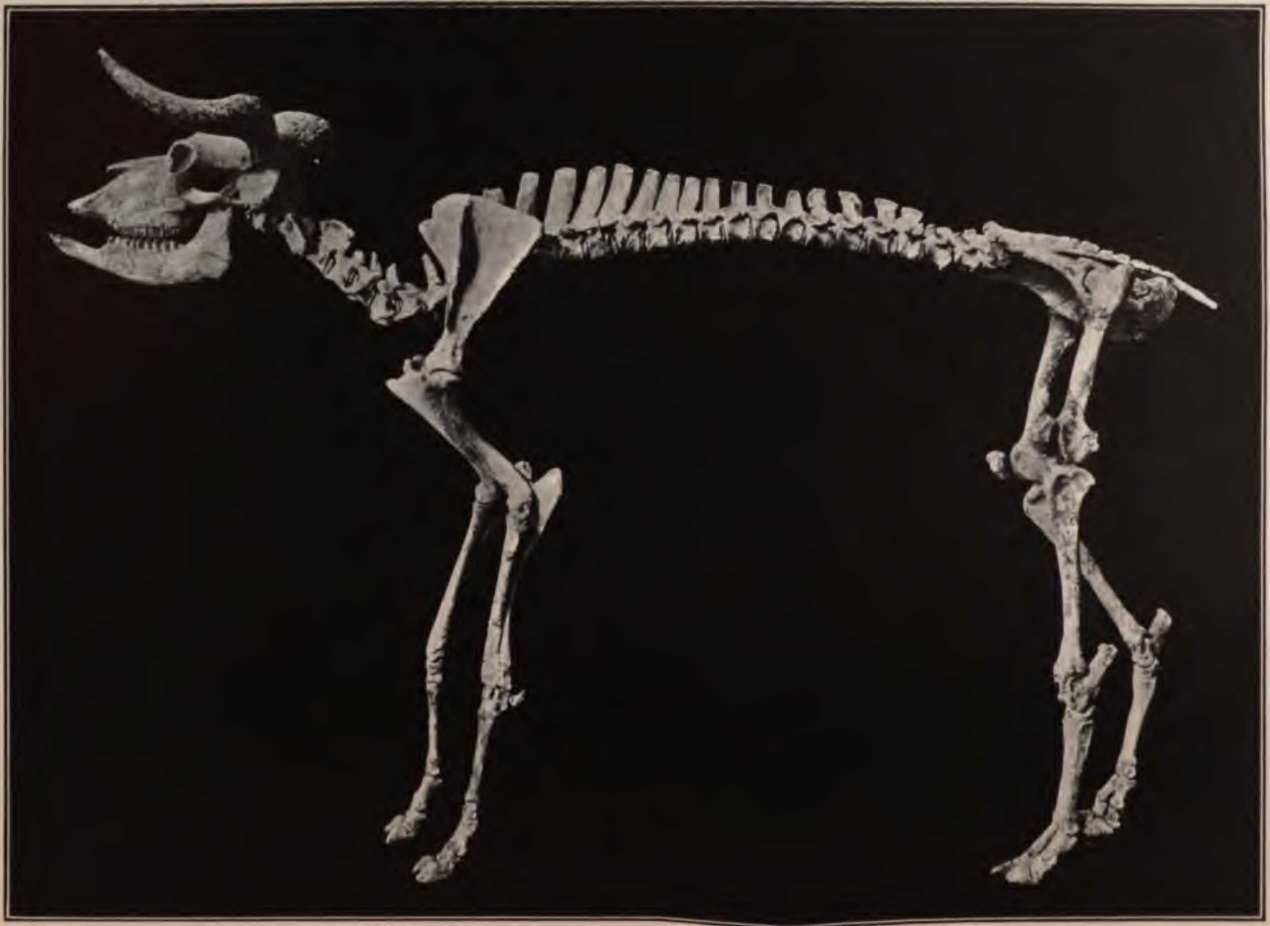
EXPLANATION [illegible] PLATE 25.

***Preptoceras sinclairi*, n. gen. and** sp. [illegible]porary mount of the type specimen, ×.081. The orbital a[illegible] nasal regions have been restored from specimen No. 1009. [illegible]e inferior premolars, the dorsal vertebrae, excepting the [illegible], and the caudal vertebrae have been restored from allied forms.



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Vol. 4, No. 9, pp. 171-175 **ANDREW C. LAWSON, Editor**

A NEW SABRE-TOOTH FROM CALIFORNIA

BY

JOHN C. MERRIAM

Some years ago Mr. Bernard Bienenfeld of San Francisco very kindly presented to the University of California a collection of fossil mammalian remains containing at least two carnivores which are new to science. One of these has already been described as the type of a new and peculiar canid genus, *Hyaenognathus*.[*] The second form, which is described below, represents a large species of sabre-tooth differing considerably from those previously described.

MACHAERODUS(?) ISCHYRUS, n. sp.

Text, Fig. 1.

The species is known only from a mandible (No. 8140 Univ. Calif. Palae. Col.) found with the type of *Hyaenognathus* near the foot of the Temblor range at Asphalto, Kern County. This specimen, like the others found with it, is covered with a very thin film of gypsum preserving the fragile bone.

The species is characterized by the great reduction of P_3, the presence of a single posterior cusp on P_4, the absence of both metaconid and heel from M_1, the shortness of the diastema, the possession of a prominent flange below the symphysial region, and the abbreviation and general robust character of the jaw.

The age of the beds in which the mandible was found is not definitely determined. Such stratigraphic and palaeontological evidence as has been obtained indicates Quaternary or late Pliocene age. In addition to this, the evidence furnished by the stage of evolution of this species and of the associated *Hyaenognathus* seems to show that they are probably not older than Pliocene.

---

[*] Bull. Dept. Geol. Univ. Calif., Vol. 3, No. 14, p. 278.

The portion of the mandible present represents a large animal, and the species must have been one of the more formidable members of the sabre-tooth group. The jaw is noticeably heavy, while the inferior flange is wider and deeper than in the typical species of *Smilodon* and *Machaerodus* but hardly as prominent as in *Hoplophoneus*. In the symphysial region the inferior portion of the anterior face is concave on either side of the median line, but the whole upper part of this face is strongly convex, and the portion of the alveolar margin occupied by the incisors is bowed far forward. In the region of the cheek teeth the alveolar margins are flared outward rather more than is common in the cats, owing probably to shortness of the jaw.

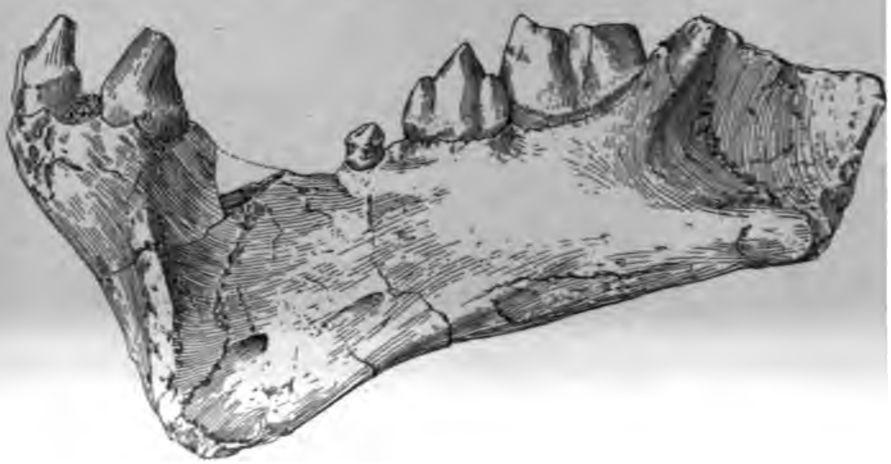

Fig. 1. *Machaerodus* (?) *ischyrus*, n. sp. × ⅔.

The dentition is $_{\overline{3}}$, $_{\overline{1}}$, $_{\overline{2}}$, $_{\overline{1}}$. I_3 is absent from both rami, but its alveolus indicates the existence of a tooth approaching the canine in size. I_2 is considerably larger than I_1. P_3 is very small and is single-rooted. P_4 possesses a single large accessory cusp on either side of the protocone, but shows no trace of a posterior basal cusp. The protoconid stands almost erect. In M_1 the protoconid and paraconid are well developed and of nearly equal size. The posterior portion of M_1 is somewhat damaged, but there appears to have been neither metaconid nor heel present. The transverse diameter is relatively large and the tooth considerably heavier than in *Smilodon neogaeus.*

Of the North American species *Machaerodus gracilis* Cope, from the Port Kennedy Fissure, resembles the Californian species in the form of P_3, while the heel of M_1 has almost disappeared. *M. ischyrus* differs from this species particularly in the shortness of the diastema and probably of the whole jaw, in the absence of a posterior basal cusp on P_4, and in the complete reduction of the heel of M_1. Judging from Cope's figure* of the type of *M. gracilis* the mandibular flange is not as prominent and the jaw as a whole somewhat weaker than in *M. ischyrus.*

Smilodon fatalis Leidy, from the Quaternary of Texas, known only from the dentition of the upper jaw, if a typical *Smilodon* as it appears to be, would differ in the structure of P_4, as also of the mandible in general.

Dinobastis serus Cope, from the Texas Quaternary, does not differ from *M. ischyrus* greatly in size and had large external incisors with a moderately elongated superior canine. The superior sectorial has a large protostyle, but the basal cusp anterior to this is rudimentary. This means that, as in *Hoplophoneus,* the posterior part of P_4 opposing it was probably relatively shorter than in *Smilodon.* The characters mentioned all suggest correlation with *M. ischyrus,* although there would at present be no justification for considering them identical.

Felis imperialis Leidy, from the Quaternary of Middle California, is known only from a fragment of the upper jaw with the third premolar. It is evidently also a short-faced form but seems to have been, as far as can be determined, of the true *Felis* type.

Machaerodus catocopis Cope, from the Loup Fork of Kansas, has a relatively larger inferior canine, a deeper mandibular flange, and is much narrower across the symphysis.

Machaerodus palaeindicus Bose, from the Siwalik beds of India, very closely resembles this species in size, in shortness of the diastema, and in the form of the anterior portion of the mandible. It appears from the figures* that P_4 has but a single posterior cusp. P_3 is, however, a heavy tooth apparently with two roots and differing much from the corresponding tooth in *M. ischyrus*.

---

* E. D. Cope. Jour. Philad. Acad. Nat. Sc., 2nd Ser., Vol. 11, Pl. 20, fig. 1.

Compared with the later machaerodont forms this species is relatively specialized in the reduction of P_3, and the apparent absence of both heel and metaconid from M_1. It is relatively primitive in lacking a second posterior cusp on P_4, and in the prominence of the mandibular flange, which is secondarily reduced in the later sabre-tooths. The abbreviation of the diastema, together with the flare of the alveolar borders, and the robustness of the mandible show that this is a comparatively short-jawed type.

The combination of characters appearing here is peculiar. The stage of development of the mandibular flange suggests an advanced form of *Deinctis*, such as is seen in the John Day *Pogonodon* or in the more primitive *Hoplophoneus* species. The reduction seen in P_3 and in the posterior portion of M_1 equals or exceeds that in *Smilodon* and *Machaerodus*. The character of P_4 is that of *Hoplophoneus* rather than of the later sabre-tooths. As far as can be judged from the characters present, this species could not consistently be referred to any of the three machaerodont groups which it most nearly approaches, viz: *Hoplophoneus*, *Machaerodus* and *Smilodon*. It may represent a new subgeneric type, in which a peculiar set of conditions suggested by the shortness and strength of the jaw have made possible the combination of primitive and specialized characters seen here. A knowledge of the cranium may bring out definite relationship to one of the known groups, and I therefore refer to the species tentatively under the more or less comprehensive name of *Machaerodus*.

---

* R. Lydekker. Paleont. Indica, Ser. 10, Vol. 2, Pl. 43.

Measurements.

Length of mandible from anterior side of I_1 to posterior side of M_1	123	mm.
Length of mandible from anterior side of canine to posterior side of M_1	107	
Width of anterior face of symphysial region	52	
Depth of jaw across the middle of the flange	58	
Depth of mandible below posterior end of P_4	36	
Length of inferior diastema	33.5	
Width of I_1 transversely	4	
Width of I_2 transversely	6.5	
Antero-posterior diameter of inferior canine	14.5	
Antero-posterior diameter of P_3	7	
Antero-posterior diameter of P_4	20	
Antero-posterior diameter of M_1	28.5	
Transverse diameter of M_1	14.5	

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BULLETIN OF THE DEPARTMENT OF
GEOLOGY
Vol. 4, No. 10, pp. 177-199 ANDREW C. LAWSON, Editor

THE STRUCTURE AND GENESIS OF THE COMSTOCK LODE

BY

JOHN A. REID

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STATEMENT OF THE PROBLEM.

In these days of rapid advance in our knowledge of the genesis of ore bodies, it becomes necessary constantly to test old ideas by new conceptions. Particularly does this apply to our recent ideas on secondary enrichments of ore deposits. The mining world is awaiting eagerly more exact knowledge on the part of geologists, that the cost of locating valuable ore bodies and developing them properly may be reduced. The structure of the Comstock lode, and the genesis of its ores, have been treated by several investigators, but even yet, many of the vital questions connected therewith are unsettled. The somewhat overdone tendency to make every ore deposit correspond to a "type," and to regard much, if not all, as already "having happened," has been productive of considerable error. Fortunately, with our ever widening view, these marks of immature science are disappearing. The Comstock is yet largely an unsolved problem, withal we know much about it, and the following notes contributed to its solution are the result of numerous short trips to the lode while the writer was engaged in other work.* The peculiar bonanzas of Virginia City have never been satisfactorily accounted for, nor the form of the lode as a whole. This paper is offered as a slight contribution to the study of ore deposits, and on account of the immediate bearing of its contents upon practical mining matters, it is issued at this time.

EAST-WEST FAULTS.

There is a much greater development of east-west faulting than has been noted by previous observers. These faults are of the utmost importance, both in the structure of the lode and in the genesis of the ores. Their importance to the lode lies in the fact that they have most to do with the notable short length of the main fissure. Their importance in regard to the ores lies in the fact that they have caused the blocking out of the wall rocks with the resultant opening to mineral solutions. These points will be discussed later. Becker* has noted the presence of such faulting, but only in a general way, and as of little importance. He says (p. 181) that the topography is due chiefly to faulting, "for on the Sutro tunnel section, at least, there is evidence of but slight erosion.* * * The ravines which furrow the range are not therefore the results of erosion, but of faulting." And again (p. 184 *et seq.*) "To the north and south of Mt. Davidson the evidences of faulting diminish (north-south faulting is meant). From the Overman far into the Sierra Nevada claim, a distance of two and one-third miles, the amount of fault has been great, and the indications unmistakable. Beyond these points the disturbance of equilibrium has been to some extent adjusted in a different manner. This is partly indicated by the union of the andesite fields, which are separated near the center of the lode by diorite. Toward the ends of the lode the dynamic action seems to have been distributed in part by the forking of the fissure and in part by the *formation of east and west cracks.*" According to Becker, these same east-west faults have their downthrow to the north. Practically nothing more is written in the monograph of Becker concerning these movements. But even now, with almost none of the old workings accessible, their large development is well shown. The most noteworthy examples are as follows:

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* The author's acknowledgments are due to Mr. James McKinty and Mr. Thomas McCormick, superintendent and foreman, respectively, of the C. & C. mine, for their aid in obtaining deep mine waters; Mr. E. E. Everett for aid in obtaining mine waters and rock specimens; Mr. M. W. Fox, and Mr. Frank Higginson, general manager and superintendent, respectively, of the Hale and Norcross; and particularly to Mr. G. McM. Ross, whose great interest in these matters lies at the bottom of this short paper. Mr. Ross was until recently superintendent of the Ophir and Mexican mines. The author wishes also to state his indebtedness to former publications upon the Comstock, particularly Becker's Monograph and King's Survey of the Fortieth Parallel. These works have been freely consulted on points not now to be determined in the mines.

Becker's Atlas should be consulted for maps, etc.

Mexican Fault.—In the Mexican ground, on the Sutro tunnel level, a very strong east-west fault was followed into the diorite of Mt. Davidson, and east into the hanging wall block for several hundred feet. No ore was developed, and the work was abandoned. Pyrite was very abundant, however, in the crushed zone. This fault was nearly vertical, with a slight inclination to the north. The throw, from all appearances seen, as striations, etc., was down to the north, making a normal fault. This line of motion is directly in line with Ophir Ravine, and no doubt was the main cause of its formation, as noted in general by Becker, quoted above.

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*G. F. Becker. Monograph III. U.S.G.S. "Geology of the Comstock Lode."

Bullion Ravine Fault.—Bullion Ravine is likewise determined by a fault plane, in this case shown largely by stratigraphic and physiographic grounds. A new geologic map is necessary to show this fully, as that of Becker * is in error at this point. In the first place, this rocky ravine shows plainly that erosion has had nothing to do with its formation, for its bottom has never been occupied by a stream. Becker notes many times that the erosion of the region has been little or nothing since the vein formation, and this is merely a case in point. Moreover, in the second place, here is a structural discordance between the walls of the ravine. The north wall is solid diorite to the summit of Mt. Davidson. The south wall is diorite farthest east, but andesite a short distance west up the ravine. The contact between the two rocks appears to be in the exact center of the ravine, but is obscured by surface wash.

Other Ravine Faults.—The ravine leading up to Mt. Butler, and Crown Point Ravine farther south, have not been examined in detail, but they partake of the characteristics of the others: typical fault ravines. Becker, though noting this, fails to give supporting evidence because he attached no importance to their structure. Such evidence is plentiful for all these east-west gulches, the most important of which is as follows:

1. The erosion of the country has been very little since the faulting, so that we are driven to look for other causes for the formation of the topographically striking ravines. In the case of Bullion and Ophir Ravines, at least, this cause has been shown to be faulting. Becker's reason for a lack of erosion seems to lie in the close similarity of the contours of the actual faulted surface with the theoretically deduced one. Further reasons, and conclusive proofs, are: (1) there is little or no removal of the thoroughly decomposed country rock near the lode; and (2) the present surface of the lode, or its outcrop, is that of the original lode apex, formed under practically no pressure from above and

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* G. F. Becker, Mon. III, Atlas, U.S.G.S.

not yet removed by atmospheric agencies. The cross-section of the upper portion of the lode, figure 1, shows this structure.

2. There is no stream worn material of any sort, except very locally, in these ravines, nor any outside their mouths where a deposit would take place by stream action. The whole region is remarkable in the lack of all such material.

No faults from Bullion Ravine in the hanging wall underground have been seen, because this area is not accessible. But on the surface, east of the lode, there are many very well defined east-west faults, some of which are filled with calcite. A few have been prospected and considerable ore extracted. The ridge running east from Bullion and Crown Point Ravines is a locus of these movements.

Cedar Ravine and Cedar Hill Cañon—These are the large gulches on the north end of the lode. Cedar Ravine is due to the surface effects of the east-west motion exposed underground in the Sierra Nevada mine, as is Ophir Ravine the surface effect of the fault shown in the Mexican mine. Cedar Hill Cañon is rather beyond the limits of the lode, yet deserves mention because it is the sharpest cut of all the fault ravines, and, like Bullion Ravine, shows the faulting by the stratigraphic relations of diorite and andesite. In both instances the andesite abuts against the diorite in a plane which occupies approximately the center of the gulches. In Bullion Ravine the andesite is south of the diorite; in the northern fault cañon, the andesite is north of the diorite. This andesite is *Becker's "earlier hornblende andesite," which has been shown to be identical with the porphyritic facies of the diorite mass.† Hence, an abutment of one of these rocks upon the other indicates a fault plane.

There appears even yet to be a doubt in the minds of some geologists, for instance, Lindgren,‡ as to the correlation of the Comstock rocks. The evidence for this correlation is, of course, of two kinds: (1) microscopical, and (2) macroscopical, including both field and laboratory work. The microscopical evidence of Hague and Iddings needs corroboration on but one possible point—that of the undoubted occurrence of fresh augite as the *chief* ferromagnesian mineral in the diorite. The field evidence, however, seems to be insufficient regarding the diabase and diorite. The present writer, through late mining work, is in possession of the facts necessary to prove beyond the shadow of a doubt the conclusions of Hague and Iddings. The Hale and Norcross tunnel into Mt. Davidson, just north of Bullion Ravine, has brought to light these facts, and also a number of structural facts of the most vital importance. The structures shown will be discussed later, and a note on the rocks will be placed near the end of this paper.

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* G. F. Becker, op. cit.

†Hague and Iddings, Bull. No. 17, U.S.G.S. "On the Development of Crystallization in the Igneous Rocks of Washoe Co., Nevada.

‡ W. Lindgren, in one of his numerous papers, states that he believes the Comstock rocks to be separate flows.

Forks of Comstock Lode.—The main forks of the Comstock lode, both north and south, are quite similar in their action on the formation of the fissure as seen to-day. Of the Sierra Nevada fork, which strikes nearly east and west, the writer can say nothing, for so much of the old ground is not open. However, the east-west slips are well shown underground in the present workings, and this portion of the lode country appears to be a locus of these movements. The large southeastward bearing "fork" of the lode which runs toward Silver City, has some peculiarities which deserve mention. In the first place, this so-called branch is not a mere fork of the lode, but as a fault continues west of the lode into the mass of Mt. Davidson west of the summit. Bullion Ravine exhibits this fault in the best manner. As already noted, the south wall of the ravine is diorite for a few hundred yards west up the gulch, when andesite appears from the bottom of the south wall clear to the top. The topography also shows the change, the diorite portion being steep and precipitous, while the andesite is smoother and of more gentle slope. The transition from one to the other is abrupt. Some prospecting has been done along this line and some ore found. The gangue in the Silver City portion or "fork," as of a few of the east-west veins east of Bullion Ravine, is largely calcite. Granting the identity of the rocks as set forth in the work of Hague and Iddings, this difference in gangue mineral from the silica of the lode proper can be accounted for, in the most probable way, by assuming a difference of age.

Fault in Andes Mine and Central Tunnel.—The Andes mine workings and the Central tunnel show many east-west faults. There is a great complexity of these in the surface workings, as is to be expected in the great lode. The largest one in the Andes cuts off sharply one of the bigger quartz bodies between the horses of diabase. Others, of less extent, but still of some size, cut across the vein proper, and act as channels for mineral solutions, as will be mentioned later. These motions are shown by clay and rolled pebbles of quartz. The east-west movements in all the surface workings are characterized by identical features. A very peculiar action is now taking place along one of these cross fractures in the Central tunnel, where there is little circulation of air, characterized by the deposition of pyrite from an acid solution.

BONANZAS.

Virginia City.—The formation of the Virginia City bonanzas is peculiar, and has never yet been concisely presented. The present developments in mining work have thrown much light upon this question of genesis. In the Virginia City portion of the lode the ore occurs not in the main fissure, but in openings or "veins" in the hanging wall, which occupy nearly vertical positions (see figure 1). These "veins" are more nearly allied to gash veins than to what are usually called "fissure veins." The "secondary vein" now so productive in the Ophir ground, has brought to light some valuable and interesting facts. (1) It has been found only in the lower mine levels, either as a mere fault zone or a productive deposit. (2) From the lines of motion preserved finely in the clay gouge, the relative movement of the walls is seen to have been nearly horizontal, whether north or south the writer is not able to state definitely. From the parts of the "vein" observed, however, chiefly on the 2050 level, it seemed probable that the motion was to the south for the east wall, dipping downward about four degrees in the same direction. This corresponds to the view that the vein itself is due to a pulling apart of the rock mass, causing the greatest openings to the north, in the concavity caused by the bending of the "vein" to the east at the north end. This northeastward swing causes the secondary opening to become nearly parallel to the Sierra Nevada fork, as shown diagrammatically in figure 2. The thickness of the ore body within this opening increases with depth up to the present time of working, and some very rich ore is being extracted. Exact distances and figures cannot be given, on account of the methods of mining now in vogue. The "vein" has been, and is, productive up to the 1800 level of the C. & C. mine and down to the 2250 level now being worked. The ore is not evenly distributed, but is in more or less well-defined chimneys or shoots, connected by material of too low grade to be worked. The form of this secondary vein, then, is a nearly vertical fissure about parallel to the main lode and east of it. In portions of this vein, particularly where opened best in stoping, a dip to the east is present.

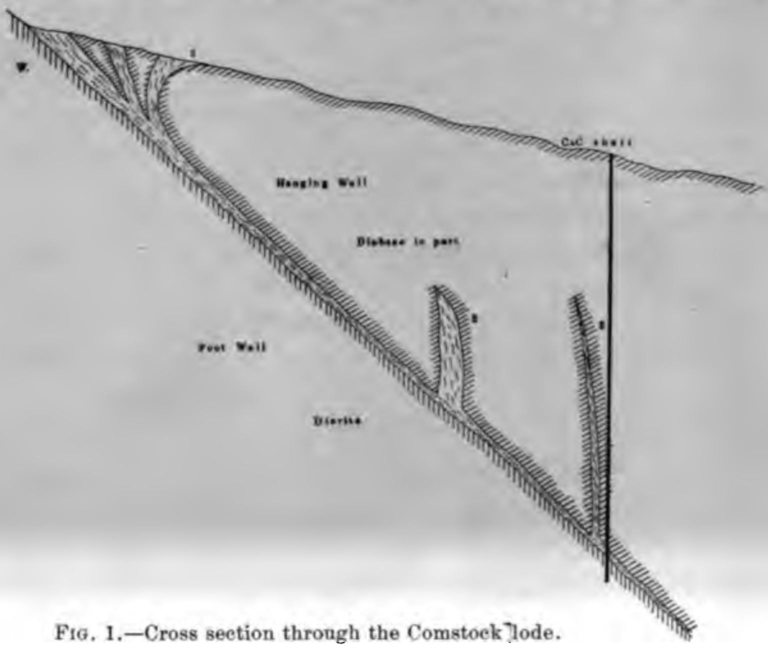

FIG. 1.—Cross section through the Comstock lode.

The lode at the surface shows an arrangement of vein filling and ore in every way due to the same causes which produced the secondary fissures at greater depths. The "west vein" and the "east vein" at the surface have been carefully described many times by previous observers,* and the fact that only the "east vein" carried values has caused much discussion. This "east vein" is merely the gash which reached the surface, thereby appearing as a vein occupying a fault plane and resultant fissure. These three gashes—the surface "east vein," the famous bonanza, and the "vein" now being worked, all have an identical origin. Their formation lies in the fact that the lower part of the hanging wall block has settled more than the upper, relative to the foot wall, and has been torn apart by the stresses developed. This form of ore deposit is rather new, and because of its evident importance deserves a distinctive recognition. The term "gash vein" is not suitable, obviously, and the name "rift vein" is suggested to cover the structure.

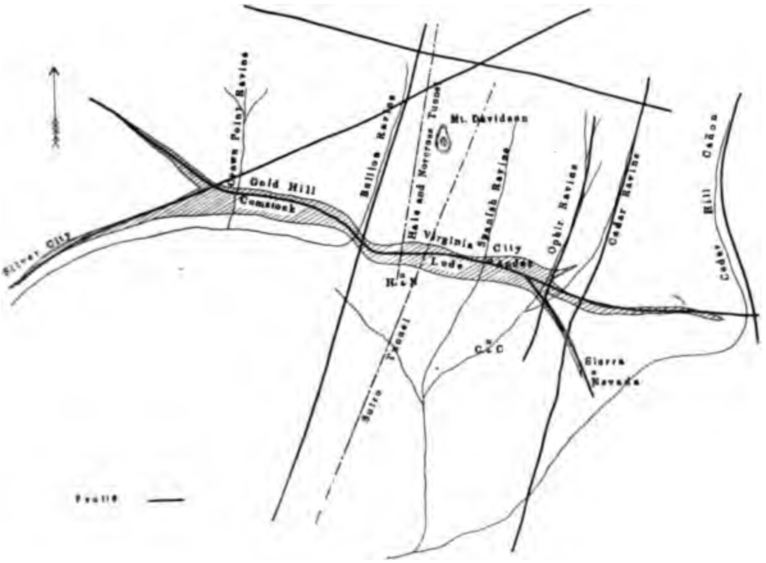

FIG. 2.—Ground plan of Comstock lode, showing disposition of faults.

Gold Hill.—The bonanzas of Gold Hill are found in the lode proper, near the east wall, and east of the low grade quartz. The differences in the form of the bonanzas in the two portions of the Comstock lode have been noted by other observers. In Becker's monograph,* von Richthofen is quoted as writing: "The ore is distributed in a different way in the northern and southern parts of the vein. * * * In the northern part the ore is concentrated in elongated lenticular masses of which the greatest axis is not far from vertical. * * * To the south the ore is concentrated in continuous sheets, the principal one of which is very near and parallel to the eastern wall." This difference in the form and occurrence of the ore bodies is a very important matter, both from a scientific and an economic standpoint. This subject, and what grows out of it, is the main reason for the writing of this short paper, for a proper view may increase the life and output of the mines very materially.

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* G. F. Becker, op. cit. Clarence King, "Survey of Fortieth Parallel," Vol. III. John A. Church, "The Comstock Lode—Its Formation and History."

One peculiar bonanza occurred in the Gold Hill group, in the Yellow Jacket mine. The explanation of this, as of the others, will be given later.

HALE AND NORCROSS TUNNEL.

The structures shown in the Hale and Norcross tunnel will be mentioned together, for the sake of simplicity. This tunnel, running N. 75° W., enters the slope of Mt. Davidson at the Hale and Norcross shaft (see figure 2). At a distance in of 1,080 feet the footwall of the lode is reached, the so-called "black dyke." 1. Proceeding in, at a distance of 3,720 to 3,750 feet, appear approximately vertical slips striking N.W.-S.E. parallel and in line with the Silver City lode as shown on the surface. A second well developed slip parallel to these occurs at a distance of 4,550 feet in from the mouth. 2. In nearly all portions of the tunnel, but particularly between the lode and 3,500 feet in the tunnel, and from 4,500 feet to the end (5,085 feet on Feb. 12, 1905), are seen slips parallel to the Bullion Ravine fault; that is, approximately parallel to the course of the tunnel itself. These indicate unmistakably evidence concerning the existence of the Bullion Ravine fault underground. 3. At a distance in the tunnel of 4,908 feet occurs a very strong vertical north-south fault. The east wall is the diorite of Mt. Davidson, and the west wall is the same rock which forms the hanging wall of the Comstock lode, the diabase of Becker. This rock continues to the face (given above), and no doubt shades into augite andesite farther west, just as in the east country. Thus the diorite of Mt. Davidson is terminated east and west by identical structures. No doubt tunnels north and south would develop the same conditions on the other two sides, as indicated by the surface structures. 4. West of this west fault just noted, the prevailing slips are perpendicular to the tunnel and dip to the west, in contradistinction to the eastward dipping slips near the Comstock.

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* G. F. Becker, op. cit., p. 17.

The west diabase, as it will be called, now shown in the tunnel, is much fractured and filled with veinlets of pyrite. Some films of galena and sphalerite up to one-eighth of an inch in thickness also occur fifteen feet west of the fault. These gave some values by assay.

DEEP ORES AND WATERS.

The ores are doubly interesting from that fact that their deposition still continues, due to faulting opening up new fissures and fractures, and from the fact that the mine waters are, for such waters, rich solutions yielding very positive results to fire assay methods. The ores are moving in two ways: upward and downward.

That the ores have moved upward at more than one time has been noted best by Becker.* He writes (page 219): "In the great California and Virginia bonanza several streaks or veins of very rich black silver ores, said to be largely stephanite, occurred. These were separated from the surrounding quartz very sharply, as if of later origin." Again (page 221) he writes: "What I have seen * * * leads to the belief that these rich concentrations were of later origin than the rest of the ore. The quartz in the C. & C. was almost everywhere a crushed powdery mass, while the thin and persistent veins of black ore running through it were very solid. A somewhat similar relation seems to have existed near the croppings, and it is not impossible that these ores were formed at the expense of others of the more usual kind at a later date, and that they occupy spaces opened in the ore masses by faulting action."

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* G. F. Becker, op. cit.

The writer had hoped to present even more conclusive evidence of successive deposition and its recency, but owing to the fact that the lowest mine workings are not open to outsiders, this became impossible. However, such evidence as already possessed is as follows:

In the ore bodies opened within the last year on the "secondary vein" now worked, some pertinent facts presented themselves. The finest specimens of ore show often very perfect crystals of stephanite and argentite coating, or wedged between, quartz crystals. Coating one side, the downward side, of all the minerals, is a thin layer of calcareo-siliceous material. Below the surface crystals of ore and quartz is a layer of quartz, resting in turn upon a second layer of calcareo-siliceous matter. This shows below it a second layer of ore, resting upon quartz crystals, and so on, the series often repeating itself several times more or less perfectly. In that portion of the ore occurring in the lower depths, from which the water has been drained but a short time, the surface layers of ore, quartz and calcareo-siliceous matter showed clear and fresh, while on standing in the open, or in the higher portions of the vein, the same minerals appeared dusty and old. In some of the vugs in the lower portion of the ore body, quite a number of small but perfect rhombohedra of calcite were found; also, as noted by Becker, old fractures in the ore, caused by faulting movements, are cemented with quartz and ore. In the ores now worked, however, the motion appears to have been a pulling apart, for brecciation, though present, is rare, and the two sides of a cemented break are usually fully complementary. This process of successive deposition is not limited to the Virginia City portion of the lode, but is found quite well developed in the Gold Hill mines, and in the calcite gangue of the Justice ore body.

Further uncemented fractures present themselves as indicators of motion up to the present time, since the withdrawal of the waters by the mine pumps. The great volume of water still entering the lower workings also contributes abundant proof of fissures kept open by late motion, for the lode proper, where cut by the shaft, is reported to have been completely filled with quartz.

Analysis of Waters.—The ore now being mined below the 2150 level, which was all below water level within a few months, shows the same conditions, with the surface minerals in the freshest possible condition, precisely as if just deposited from solution. A notable fact of these lower deposits is the greater proportion of gold to silver than was found in the ores above. On the 2050-foot level and below, considerable free gold was found. The actual process of deposition cannot well be watched, hence as the best substitute the deep waters from the 2250 level of the C. & C. shaft were analyzed and assayed, to determine if they were able to do such work as indicated. They are exactly suited to this, as the following facts will show. The water is the typical deep water of the Comstock lode whose temperature has reached as high as 170° F., and is always over 116° F.:

ANALYSIS OF MINE WATERS.*

	Grams per liter.
SiO_2	0.1334
Al_2O_3	.0025
Fe_2O_3	.0091
CaO	.1404
MgO	.0097
SO_3	.3957
Cl	.0190
CO_2	.0150
K_2O	.0643
Na_2O	.1765
Total solids	.9656

Assay of Waters.—From an evaporation of 10 liters of the water, the following assay values were obtained. This work was most carefully done, and the results are accurate. The gold buttons obtained by parting were measured by a microscope and their weight calculated. This result may therefore be a trifle high, because of the possibility of the gold being slightly porous. The litharge used was remarkably pure, a number of test assays on 100-gram charges failing to show the merest trace of a button under the highest powers of the microscope.

Silver	2.92 mg. per ton of solution
Gold	0.298 mg. per ton of solution

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* Analysis by N. E. Wilson, Professor of Chemistry, University of Nevada.

The analysis of the water showed it to be an alkaline sulphate and carbonate solution containing a large amount of lime. The presence of chlorine is important as affecting the gold in solution. The CO_2 determined is low, for on standing, some of this gas is given off and the silica separates out in sufficient amount to render the water milky. The writer has been unable, for stated reasons, to test the water in the mine. The jugs of water stood for from 48 to 64 hours before testing, hence the figures for the carbon dioxide need considerable correction. On evaporating the water and moistening the residue, a strong alkaline reaction is obtained by litmus paper.

SURFACE ORES AND WATERS.

The ores are moving downward by the leaching action of the acid surface waters. In this way they are extracted from their containing rocks and redeposited below. This process in the past has produced the striking "nodular" ores of the Andes mine, noted by King[*] as occurring just below the level of ground water. These ores are now in their turn being attacked and again being carried below. A striking example of the ore deposited by the vadose waters was exposed on one of the levels of the Andes mine. The presence of east-west slips has already been noted as occurring here, and one of these, dipping south 60°, had opened sufficiently to allow the free circulation of water. The slip had cut across all other rocks, vein and country, and was filled with about two inches of solid coarse black sulphides of lead and silver. This small sheet of ore pinched out toward the bottom of the drift, but broadened above. The grain of the ore, and general characteristics of ratio of lead to silver, etc., were all different from the ore which occurs below, deposited from the deep circulation. The nodular ores consist typically of nodules ranging in size from that of a pea up to a foot in diameter, and composed of rich black sulphide ore in a matrix of fine crystals of quartz. Each nodule is completely surrounded by barren quartz, which at times may penetrate the nodule along later cracks. These quartz crystals are built upon the nodules as centers, giving them a radial arrangement.

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[*] Clarence King, "Survey of Fortieth Parallel," Vol. III.

All the facts relating to these peculiar ores tend to confirm the view of their deposition resulting from the intermingling of oxidized surface waters with deep alkaline unoxidized solutions. They are known to occur nowhere else on the lode in any mine workings, although the exploration within the croppings is very little in amount.

The acid surface waters which are now doing so much work, have covered the walls and cross-cuts of the Andes mine with from six inches to a foot of sulphates containing traces of gold and silver. The chief salt is the magnesian aluminum sulphate, with also large admixtures of iron and copper, which results in a remarkable variety of colors. The workings of the Central tunnel likewise shown these sulphates, but in general the circulation of air is too rapid to allow of their great formation except in some favorable localities. The composition of these salts is shown as an average in the water analysis following. In the Central tunnel in one particular spot, where the surface waters are not fully oxidized, ferrous sulphate and pyrite are being deposited at the present time. Some sulphates are being formed here in delicate needle-like crystals containing a large amount of the ferrous salt. Bright, well-formed cubes of pyrite and some few dark sulphides, too small in amount to admit of testing, occur below and within the sulphates. Not infrequently a little crystal of pyrite tips a needle of sulphate where the solution is plentiful. Also, almost solid masses of the sulphide are found within the wall in the partly decomposed country rock. The water is descending along an east-west slip which dips to the south. The clay, or clayey rock, upward along this slip is full of pyrite, but this mineral is heaviest near the wall of the drift where the solution is able to cover more ground. The clays of the upper portion of the lode are all found to contain well formed but small crystals of pyrite containing some value. There is probably but one process responsible for all this, and a possible reaction of the surface waters to produce such a result may be expressed as follows:

$$FeSO_4 + 2H_2SO_4 + 7H_2SO_3 = FeS_2 + 8H_2SO_4 + H_2O.$$

This reaction is, of course, possible only when there is an insufficient supply of oxygen, as occurs locally in this part of the Central tunnel.

The water surrounding the sulphates and pyrite being deposited, is strongly acid, the most so where the pyrite is heaviest. As the wall is worked into, the acidity becomes perceptibly less. The ferrous sulphate appears to exercise the necessary protecting influence over the pyrite to save it from attack by the free acid or further attack by the small amount of free oxygen present.

Analysis of Waters.—The analysis of the vadose water, from Central tunnel, taken from a dropping stream out of the wall on the lower level, is as follows:*

	Grams per liter.
SiO_2	0.6160
Al_2O_3	18.2140
Fe_2O_3	7.1786
Mn_3O_4	1.2500
CaO	1.7400
MgO	10.8108
CuO	0.1850
SO_3	70.1154
Cl	0.1276
H_2O	trace
Na_2O	0.7209
Total solids	**110.9583**
Free H_2SO_4	**125.0804**

The remarkable properties of this water are evident. Silica is noticeable in amount, in spite of the strongly acid solution. The salt is seen to be essentially a magnesian ferric aluminum sulphate, with lime, copper and manganese. These mine solutions vary, and the writer has taken from the roof of some of the old stopes stalactites of quite pure copper sulphate. The water analyzed was a fully oxidized solution; the water depositing the pyrite is only partially supplied with oxygen.

Assay of Waters.—The assay of this vadose water gave the following results: 250cc. portions were used for each test.

Silver	188.0912 mg. per ton of solution
Gold	4.1528 mg. per ton of solution

It is necessary again to note the fact that some of the east-west veins which exist east of Bullion Ravine on the line dividing the Virginia City portion of the lode from that of Gold Hill, are filled largely or wholly with calcite gangue. The same mineral acts as vein-filling in the Silver City lode. Becker [*] favors the view that the difference in gangue mineral between the Silver City lode and the main vein, is due to differences of country rock. But as the calcite veins exist in the augite andesite east of Bullion Ravine, this idea cannot hold. On the fact, however, that the two lodes are due to different faults, a more probable conclusion is that the deposits are of different age. The proof of this lies in the examination of the point where these two lodes intersect, which is not now possible. Published reports and maps are insufficient as a basis for judgment.

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* Analysis by N. E. Wilson.

A further fact of importance regarding the lode, in the Virginia City portion especially, is that the width of the vein is often little or nothing in the lower levels. Moreover, the west wall is not well defined in all places, because of a complexity of slips in the west country. This portion of the ground in all the lower levels has not been thoroughly prospected, in spite of the many thousand feet of mine workings.

ROCKS OF HALE AND NORCROSS TUNNEL SECTION.

A full report of this section is not yet ready, nor would it be proper at this time before the tunnel is complete. A full set of rock specimens, taken every fifty feet, and oftener over important places, is now being collected for the writer. However, the importance of the main facts concerning the rocks within Mt. Davidson is too great to allow their complete reservation at this time. These facts are briefly as follows:

1. The Hale and Norcross tunnel (see figure 2) strikes the lode footwall at 1,080 feet in from its mouth. The first wall rock encountered in the foot is the well known "black dyke," of decomposed basalt,[†] a few feet in width. Beyond this, in to a distance of 1,270 feet, is a fine-grained, dark rock looking much like a fresh augite andesite. In the Mexican ground, in the crosscut tunnel mentioned above (page 3), the same rock occurs east of the lode, shading into diorite to the west. Under the mi-

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[*] G. F. Becker, op. cit., p. 220.

[†] Hague and Iddings, Bull. No. 17, U.S.G.S.

croscope the rock is seen to be an augite rock of a texture between an augite andesite and a diabase, yet which in spots is that of a fine-grained augite diorite. The augite is fresh, and in more or less irregular grains or in well formed crystals, with high birefringence, very faint pleochroism, and an extinction angle of from 40° to over 50°. The feldspars are well formed, and crystallized at about the same time as the augite. They all show extinction angles of over 20°, and are labradorite. Some few flakes of biotite and grains of quartz are also present. At 1,200 feet in there occurred what appeared to be a thin dyke of diorite one-half an inch wide, intrusive in the dark augitic rock. No well defined boundaries were shown, however. Farther search showed many more such dykes at 1,250 feet, of apparently the usual pinkish diorite, intrusive in the dark rock. The microscope revealed the fact that the two rocks differ only in coarseness of grain and alteration of feldspar, and that the change from one to the other is gradual. The pinkish diorite was thus found to be an augite rock with some of the large augites altered to uralite, but identical in all particulars but grain with the dark-colored stone. The dyke at 1200 feet seemed to show that some motion took place in the mass when still plastic, as very often happens in igneous magmas, for the transition from the fine to coarse grain was more sudden than in the small dykes at 1250 feet. Beyond 1250 the ordinary type of pinkish, coarse-grained diorite comes in gradually. The microscope proved this to be a true augite rock also, with many crystals of fresh augite, and more such changed to uralite in part, and partly to chlorite, epidote, and magnetite. This pinkish rock continues on until at 1358 feet a small mass of diabase occurs, from six to ten feet wide along the tunnel. One side of this diabase is bounded by a slip and some brecciation; the inner side passes into diorite very gradually.

Again at 2650 feet, and at 3725 to 3760 feet, diabase occurs, in the latter case particularly, shading beautifully into diorite by all possible gradations. Specimens taken here are either diabase, or diorite, or both, as one may choose to call them. And the rock is all augitic, though none of this mineral is wholly fresh. The rock is much fissured and jointed, so that the alteration of the minerals has proceeded quite far.

At 3350 feet an entirely new rock, as far as macroscopical appearances go, begins gradually to appear. This rock is of the texture of the pinkish diorite so common on the surface, but is almost black in color, with the peculiar luster of augitic rocks. The microscope shows it to be a true augite diorite, precisely the same rock as the surface stone except that its augite is fresh or only slightly altered. The usual amount of free quartz is present, as in all these rocks, and likewise some few flakes of biotite. This phase of the diorite mass appears to be the core of Mt. Davidson.

Proceeding farther in the tunnel, the pinkish rock tends to reappear gradually beyond 4500 feet, and at 4700 feet a peculiar mottled facies shows itself. This has not yet been investigated, but is merely a variety of the diorite. At 4908 feet in, the "west fault," as it will be called, occurs, beyond which appears the "west diabase." The rocks of this section, when properly studied, will complete the work of Hague and Iddings east of the lode, and will serve to bring into greater relief the admirable work of these men.

CONCLUSIONS.

Form of Lode.—The Comstock lode is divisible on structural grounds into two main portions: (1) the Virginia City portion, and (2) the Gold Hill portion. The Silver City fault and lode, or "branch," as now called, is a distinct unit, probably of later age. The grounds for this belief are, as seen, the facts of it being a distinct fault, and that the vein filling is different from that of the Comstock lode proper. The only grounds for a belief in a later age are those of structure; it is well shown that much faulting took place after the first formation of the main lode, and to combine all the facts presented it is necessary to assume a period of faulting not coincident with that which formed the bonanza gashes, but later than the first faulting. In this country of great and long continued faulting such an assumption is not without a good basis.

The Virginia City portion of the lode is bounded on both north and south by a series of east-west faults. Also, to the north, some forking of the lode occurs, with one strong branch bending to the east in the Sierra Nevada ground. The faults or slips to the south are those approximately in and east of Bullion Ravine. But few of these east-west fractures contain much secondary mineral. The few which do become veins are largely calcite bearing, and probably of different age from the others. Between these two lines of east-west motion is located the Virginia City portion, differing from the other part in having a greater relative movement of the foot and hanging walls. This motion has been so great that an unequal movement of the hanging wall block was produced, the bottom moving farther than the top, with consequent rupture. These ruptures produced the secondary vertical gashes, or veins of rifting. This motion causing rupture, however, was distinctly later in age than the first vein forming movements. Hence, when the secondary openings were formed, they were filled with concentrations from the previous deposits as well as with original supplies from great depths. And there is no good reason for assuming that either the movements or the ore deposition have ceased, but rather all facts tend to confirm the idea that ore is yet being moved from place to place in the greater depths as well as fresh supplies from below being brought up by the hot waters.

In the Gold Hill portion the relative movement of the walls of the lode has been less; there have been no rift veins formed, and the ore bodies are within the lode walls, near the hanging. The same two periods of deposition of vein-filling were present here, the bonanzas occupying later fissures near the hanging wall of the earlier vein. No doubt deposition is still progressing in depth here, though not enough mining work has been done to allow a definite statement in this regard. The one exception to form in this portion of the lode, in the Yellow Jacket mine, was due to the fact that the vein, in its proper plane, did not reach the surface, so that the relative movement of the hanging wall block downward was taken up near the surface by a gash or rift.

Deposition of Ores.—On account of the importance of the subject, a reiterated statement is not out of place regarding the two periods of ore deposition. Had the second of these periods not existed, there would be practically no ore on the Comstock, hence the relations of these two must be of vital concern. The first period of vein-filling was due to the primary faulting, and low-grade materials were placed in the open fissure. The second and later period opened new fissures, rift veins in Virginia City, and openings within the vein in Gold Hill, in which the rich concentrated ores of the bonanzas were deposited. This second period probably continues in the depths, as it would surely do above were the lode still intact from man's hand. The details of this ore deposition have not yet been thoroughly studied out, nor can they be until our knowledge of the physical chemistry of the subject is more complete.

Location of Bonanzas.—The deep ore bodies of Virginia City have been, and will be, found within the hanging wall, in more or less vertical fissures, of which the surface "east vein," the Great Bonanza, and the vein now being worked, are examples. More such bodies should be found by properly-driven cross-cuts and drifts lower down and to the eastward. There is also a large stretch of the lode above the 2150 feet level which has not been thoroughly explored. The probable reason for the peculiar rifting of the hanging wall block is that the cementing of the first fracture by quartz, and the concomitant weakening of the hanging wall by the leaching action of the ground waters, enabled the later stresses to fracture the hanging wall block as it is found. The reason for believing in the existence of still deeper similar rifts filled with ore is that the surface for two miles eastward from the lode shows the hanging wall block to be greatly altered by the action of hot waters, and therefore weakened. The Sutro tunnel section corroborates this, and the mine workings also show the rocks east of the lode not to be solid nor unaltered.

Also, there is considerable concentration of ore taking place from above by the surface, or vadose, waters. These ores will occur on or near the footwalls of the numerous branches of the lode which outcrop on the surface, within a few hundred feet of the outcrops. Such material is low-grade, however, and, in the main, not yet available because of the high cost of mining and milling. A body of future reserves is thus assured. The low-grade of these ores has been proved by numerous assays. Further, the west wall of the lode has never been thoroughly investigated, and such work might prove very profitable.

Structure and Genesis of Mt. Davidson.—Mt. Davidson is a diorite mass bounded on all sides by faults, and has risen relatively to the surrounding country. The Comstock lode occupies the fissure made by the east fault bounding the mass. The west fault now shown in the Hale and Norcross tunnel is not occupied by a vein in the tunnel, because the compressive stresses have been too great. Farther search, both along this fault, and particularly farther west, may easily result in the finding of ore. There are no reasons for assuming the non-existence of ore in the west country, nor elsewhere in the faulted region surrounding Mt. Davidson, especially to the south, where the country is more fractured and broken.

A further word concerning Mt. Davidson may not be amiss, although the subject has not been fully investigated, on account of the time necessary. On the Carson sheet* the mass of Mt. Davidson is seen to be a roughly rectangular mass approximately two by one and one-half miles, with the major axis north and south, bounded on all sides by steep slopes. The eastern slope is noted for the Comstock lode. The surface of this mountain mass is that of an old eroded region, as noted by Becker † (page 184 *et seq.*), which has been uplifted above the surrounding country. One standing on the summit of Mt. Davidson cannot fail to be struck with the mature character of the topography. This eroded, gently rolling surface exists well preserved in the Sierra Nevada to the west, now broken and displaced by later faulting action. The history of the Sierra and Virginia ranges is identical in the main features. These statements will be proved by a citation of facts in a subsequent paper now in preparation. The results of this conception are obvious and far reaching. The location of the Comstock is well known on the east. On the south are other ore bodies in the American Flat region, but all of the south has not been prospected. One well developed west fault has recently been shown in the Hale and Norcross tunnel, and more will follow. The maximum faulting on the west is farther to the west than the present face of this tunnel. To the north several quartz bodies are known to exist on the surface over the broken country, but the details here are not yet known. There is abundant reason for suspecting the existence of ore on other sides of Mt. Davidson than the east.

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* Carson Topographic Sheet, U. S. G. S.

† G. F. Becker, op. cit.

University of Nevada,
Reno, May, 1905.

NOTE.—At the present date, July 6th, 1905, it can be definitely stated that ore has been discovered in well-formed veins in the Jumbo District, about two miles west of the Comstock Lode, on the west slope of the Davidson Plateau. Also, the Hale and Norcross Tunnel, though not yet far enough west to develop ore bodies, has cut into a large flow of warm water in the fissured "west" country.

ASTOR, LENOX AND
TILDEN FOUNDATIONS.

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THE DIFFERENTIAL THERMAL CONDUCTIVITIES OF CERTAIN SCHISTS.

BY

PAUL THELEN.

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INTRODUCTION.

We know that in general the physical properties of crystalline substances are functions of direction, that is, crystallographically similar directions show like physical properties (conductivity for heat, light, and electricity, dilatation, cleavage, hardness, solubility, etc.), while crystallographically dissimilar directions may show unlike properties. Even isotropic substances, for instance, possess cleavage. Here the behavior toward light is the same in all directions, while the cohesion is not. These phenomena, observed in all crystalline bodies, are referred back to an internal molecular structure. This structure is suggested to us, too, by the .external geometrical form of the crystals.

In the case of the heat and light conductivities of crystalline bodies, we assume the properties of the ether to be affected by this molecular structure. Increased conductivity in one direction is explained by an increase in the elasticity e of the ether in that direction, the density d remaining constant (Fresnel); or, equally well, by a decrease in the density, the elasticity being constant and equal to infinity (Rayleigh) or equal to $-K$ (Thomson) where K corresponds to the modulus of shear or coefficient of rigidity. This is in accordance with the old elastic solid theory where $V=\sqrt{\frac{e}{d}}$. The modern electro-magnetic theory of Clerk Maxwell teaches that $V=\sqrt{\frac{1}{Ky}}$, where K is the specific inductive capacity and y is the permeability, and the value of this radical increases with an increase in $\frac{1}{y}$ or with a decrease in K. Whichever one of these views we adopt, we assume always fundamentally that some property of the ether is affected by any regularity in the arrangement of the molecules. If we arrange a number of material particles in orderly fashion we *have not* affected the properties of the ether; if, as is probably the case in crystalline solids, we arrange a number of aggregates consisting of many molecules each in orderly fashion, we *have* affected the properties of the ether. Where is the dividing line? The question that suggested itself was this: If light and heat conductivity in a crystal are functions of internal *molecular* structure and of conditions of internal strain, will the heat and light conductivity of a rock depend similarly, in part, at least, upon its internal *crystallographic* structure and its conditions of internal strain?

In a schist which has been dynamically metamorphosed, we assume that the internal strain has been relieved by the recrystallization of the constituent minerals; but this recrystallization has set up in the rock a definite crystallographic structure comparable to the definite molecular structure of a crystal. Will this *structure* in itself affect the thermal conductivity of the rock? Can we here consider the crystal as the physical unit even as we have heretofore considered the molecule or aggregation of molecules?

The answer seems to be very definitely, No! that the thermal conductivity of a rock is not in any way a function of the orientation *in itself* of its mineralogical constituents, but is entirely the result of the integrated thermal conductivities of the individual minerals.*

This result was the probable one. Experimental verification is, however, always valuable and grateful.

When sufficient evidence shall have accumulated to verify the above answer and the analogous statement concerning dilatation effects, namely, that the dilatation coefficients of a schist are unequal in different azimuths and computable from a microscopic examination of the rock structure and a knowledge of the dilatation coefficients of the constituent minerals, we shall have a new and potent tool to take into account in any discussion of deformations of the earth's crust by thermal effects. Suppose, for example, a bed of crystalline schists undermined by a molten magma. If the coefficient of thermal expansion in one direction in the overlying plane is greater than in another direction perpendicular to the first, and in the same plane, then we shall have a definite tendency toward differential deformation. The effects will duplicate those due to compression by other agencies. Take, for instance, a quartzose rock. This is a poor example since quartz, though often found in schists with the longer dimensions of the individual grains roughly parallel, is yet never found with its *c* axes parallel. But the physical constants of quartz have been worked out and can furnish the basis of a numerical computation. For the range from 0° to 100° C, Fizeau gives that parallel to *c*,

$$l_t = l_0\ (1+.0000072\,t+.0000000081\,t^2)$$

and perpendicular to *c*, $l_t = l_0\ (1+\ .000013\,t+\ .000000012\,t^2)$.

If we make $t = 100°C$, we have $l_{100} = l_0\ (1.00078)$ parallel to *c* and $l_{100} = l_0\ (1.00141)$ perpendicular to *c*.

Waldemar Voigt determined Young's modulus in various directions for quartz, and his results bear out the conclusions of Savart[*] that the elastic properties in various azimuths possess the asymmetry characteristic of rhombohedral tetartohedral crystallization. His results were computed from bending tests, with the load applied in the middle, and E was the unknown quantity in the bending formula $y=\frac{P\,l^3}{4E\,b\,d^3}$.

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*Such effects as total reflection, for instance, are probably not entirely negligible. A Sillimanite needle, surrounded entirely by minerals of lower index of refraction than its own, would propagate in the direction of its length only any heat ray that entered a cross section of the needle nearly parallel to its length. The effect may be observed by looking lengthwise through a solid glass tube which points toward a source of light—light and heat waves obeying the same laws in general.

The values of E[†] expressed in grams per sq.mm. were:

$E_0 = 10{,}304{,}000$ parallel to c.
$E_{-45} = 13{,}050{,}000$ perpendicular to $-R$.
$E_{+45} = 8{,}405{,}000$ perpendicular to $+R$.
$E_{90} = 7{,}850{,}000$ perpendicular to c.

For linear dilatation, E or $M=\frac{Fl}{ea}$ or $e=\frac{Fl}{Ma}$.

For thermal expansion, $e=l\,(t_2-t_1)\,c$.

Combining, $F=Ma\,(t_2-t_1)\,c$, which measures the force to be applied to keep the body from expanding under the given conditions. If we take a cubic foot of quartz in which the c axes are all parallel, we shall have the force of expansion for a rise of temperature from 0° to 100°C to be

$$\frac{10{,}304{,}000}{453.6\times 2000}\times(12\times 25.4)^2\times .00078=820 \text{ Tons per sq. ft. parallel to } c$$

and

$$\frac{7{,}850{,}000}{453.6\times 2000}\times(12\times 25.4)^2\times .00141=1140 \text{ Tons per sq. ft. perpendicular to } c.$$

These results are remarkable, but not nearly as startling as they might be. For here the modulus is large where the thermal expansion is small, and the two tend to neutralize each other.

A case that would come nearer to some of the schists studied would be one in which mica or hornblende is the main mineral. In many mica schists the micas all lie in the same plane, having their c axes parallel, while in some hornblende rocks the hornblendes have all three axes roughly parallel.

Gypsum has in the plane of its clinopinacoidal cleavage moduli whose values vary from 3.1×10^6 to 8.6×10^6[‡]; but values perpendicular to the cleavage have not been worked out because the bending test can not be applied here and no other method has been successfully substituted for it. Mica shows less variation in the basal planes and values perpendicular to this have also not been worked out. The physical constants of hornblende have not yet been determined. These two minerals will doubtless show much greater differential effects than the quartz does, and they are of more than theoretical importance.

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[*] Pogg. Ann. Bd. XVI, p. 206, 1826.

[†] Taken from his remarkable paper in V. 5 of the Beiblätter des Jahrbuches für Cryst. Min. u. Paleont.

[‡] L. A. Coromilas. Über die Elasticitätsverhältnisse in Gyps und Glimmer. Inaug. Dis. Tubingen. 1877. Reviewed in Zeit. für Kryst. V. I, p. 407.

The volume relations are interesting as they give an idea of the relative insignificance of the synclinal and anticlinal deformations necessary to relieve the strains set up by thermal changes. If we imagine a cubic mile of quartz similar to the cubic foot discussed and heat this up for a thousand degrees, we get the expansion in the two directions (assuming rather dubiously that Fizeau's values for the coefficients of expansion as determined for the range from 0° to 100° hold for this range as well) to be

$5280 \times .0078 = 41.2$ ft. parallel to *c*, and

$5280 \times .014 = 73.9$ ft. perpendicular to *c*.

A similar block of augite would give expansions of 84.5, 32.7 and 96.0 ft. per mile in the three directions which correspond to the three main axes of thermal expansion. Calcite shows much greater discrepancies since *c* is negative in one direction, the values being

$l_t = l_0 (1 + 0.0425\, t + 0.0708\, t^2)$ for parallel to *c*.

$l_t = l_0 (1 - 0.04057\, t + 0.0704\, t^2)$ for perpendicular to *c*.

Hence the expansion for a thousand degrees (making the same dubious assumptions) would be

$$5280 \times (.025 + .008) = +176 \text{ ft.}$$

$$5280 \times (-.0057 + .004) = -8.9 \text{ ft.}$$

Again, one result of the differential thermal conductivities is its effect upon the outlines of the zone within which the metamorphic influence of an intrusive magma would make itself felt.

THE USE OF THE WAX-FIGURE FOR THE DETERMINATION OF THE RELATIVE HEAT CONDUCTIVITIES.

J. Ingen-Houtz* was the first to suggest the use of wax-figures. His work was done over a hundred and twenty years ago; although his numerical results were of no value whatever, yet his name is remembered because he was the first to outline the method. He took thin slices of crystals cut so as to have two faces parallel, bored a hole perpendicularly through the center of each one, coated both faces with wax and through the hole ran a needle or wire which could afterward be heated by conduction or by an electric current.

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* J. Ingen-Houtz. Sur les métaux comme conducteurs de la chaleur. Jour. de phys. 34, 1789.

Sixty years elapsed before anything more was done. Then de Senarmont* took up the work. His results on quartz in particular and on about a score of other minerals in general have become classic, and later investigations through half a century have not cast any doubt upon their accuracy. Senarmont used a silver wire which he heated at one end. The wire was either driven through a hole in the section, or its end was lowered perpendicularly upon the face of the crystal. The wax surface was shielded from any heat which might radiate from the flame or wire. In his later work, Senarmont used also a hollow tube in place of the silver wire. This was heated by passing a current of hot air through it.

He found that every section of an isometric crystal and every section perpendicular to *c* of a uniaxial crystal gave circular wax figures. This means for the First System a spherical heat-conductivity ellipsoid, and for the Second and Third Systems an oblate or prolate ellipsoid of revolution with the *c* axis as the axis of revolution. Further experiments with crystals of the Fourth, Fifth and Sixth Systems gave triaxial ellipsoids in all cases. In the orthorhombic system, the three main axes lay in the pinacoids, and hence were parallel to the crystallographic axes. In the monoclinic system, one axis was parallel to the orthodiagonal; and in the triclinic, not even one axis was uniquely located by a knowledge of the orientation of the crystallographic axes. Thus the orientation of the axes of elasticity for heat conduction bears in every case a relation to the directions of the crystallographic axes which is entirely analogous to that which the orientation of the optical axes of elasticity bears them.

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* The scientific literature of the day is replete with brief outlines of the results of his work. Ann. chim. phys. 1887, 1848, 1850; Ann. Pogg. 1848, 1849, 1850, etc.; Wied. Ann. of the same period.

Senarmont's values for the ratios of the axes of his wax figure ellipses in sections parallel to *c* in some uniaxial crystals are given here, and reference will be made to these figures later. The figures of the first column are proportional to the axis parallel to *c*, and the axis perpendicular to *c* is taken as unity.

Quartz	.76	1.00
Tourmaline	1.27	1.00
Calcite	.90	1.00
Rutile	1.10	1.00

These were some of the results of Senarmont's work, results both general and specific. But this genius of the laboratory was unable to state definitely whether or not there was any relation between the thermometric conductivity in any direction and the length of the radius vector of the ellipsoid in that direction. His results, as interpreted by himself, merely showed that the thermometric conductivity varied in the different directions and that the wax figures were symmetrical when there was within the crystal no axis of elasticity which made an oblique angle with the surface. (In this case, an oval was produced.)

We can at once come one step nearer our result by getting the relation between the thermal conductivity K, and the thermometric conductivity k. It is apparent that the rise in temperature, by means of which thermometric conductivity is measured, will be proportional to the thermal conductivity K, and to the reciprocal of the thermal capacity $d \cdot s$, where d is the density, and s is the specific heat.

We have, then, $k = K/d \cdot s$.

This agrees with Tait,[*] who uses s to represent thermal capacity and writes $k = K/s$. It also agrees with Gruenstein and Giebe,[†] who have $a^2 = K/d \cdot s$, where the thermometric conductivity is expressed by a^2. Such was probably the authors' intention, since a is generally used for distances, and could in this case be proportional to the distance from the point source of the heat to the point whose temperature is under consideration.

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[*] Theory of Heat, Tait.

[†] E. Giebe. Über die Bestimmung der Wärmeleitvermögens bei tiefen Temperaturen. Verh. der D. P. Gesellschaft, 1903.

We have, then, for one direction, $k = K/d \cdot s$;
and for another direction, $k' = K'/d \cdot s$;
and, since density and specific gravity are not directed quantities, and are constants for any one specimen, we have $k : k' = K : K'$.

The rest of Senarmont's question was first answered by Duhamel* on the basis of a theory which he had worked out in 1828. The foundation of this theory was the hypothesis that heat is conducted within a solid body by radiation from one molecule to another. Duhamel came to the conclusion that the ratios of the axes of an isothermal ellipsoid are equal to the ratios of the square roots of the thermometric, and hence also thermal, conductivities in the corresponding directions.

In the same year, G. G. Stokes† came to the same conclusion from a perfectly general discussion of the conduction of heat in crystals, in which no assumption was made as to intermolecular radiation or any other means by which the heat might be conducted. His differential heat equations and the beautiful line of reasoning by which he finally gets his result would be out of place in this paper. His result is that the axes of the ellipse are proportional to the square roots of the thermal conductivities, and accurately so, for the shape of the ellipse is unaffected by the losses from the surface.

The removal of the theoretical difficulties which had prevented the interpretation of the laboratory results, at once gave good opportunities for satisfactory research work.

E. Jannetaz‡ found that boring holes into the sections was a tedious and unsatisfactory business, so he used a small platinum bullet through which he sent an electric current by means of two fine platinum wires. He took readings on a very large number of minerals. Liebisch[*] says of Jannetaz' attempt to show a dependence of the thermal conductivity on the cleavage of the crystals, that the conductivity is symmetrical with respect to other properties than that of cleavage,—"dass die Wärmeleitungsfähigkeit andere Symmetrieeigenschaften besitzt als die Cohäsionseigenschaften." This matter will be brought up again.

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* J. M. Duhamel. Sur les équations générales de la propagation de la chaleur dans les corps solides dont la conductibilité n'est pas la même dans tous les sens. Jour. de l'école polytech. 13, 356, 1832.

† G. G. Stokes. On the conduction of Heat in crystals. Cambridge and Dublin Math. Journal. 6, 215, 1851.

‡ E. Jannetaz. Des Surfaces Isothermes en minéralogie et en géologie. Notice sur les travaux scient. de M. E. Jannetaz. Meulan, 1882.

E. Jannetaz. Sur la propagation de la chaleur dans les corps cristallisés. Annal chim. phys. (4) 29, p. 5, 1873. Bull. Soc. Géol. de France, 1873–1878; 1881. Journ. de Physique, (1) 5, pp. 150, 247, 1876.

Roentgen[†] obtained his ellipses by an entirely unique method. He blew his breath upon the polished surface of the crystal, set a warm, pointed rod perpendicularly upon it, removed the rod and hastily spread lycopodium powder upon the surface. Where the moisture from his breath had not evaporated, the powder stuck; and on turning the crystal plate over, the loose powder could be knocked off from the center, thus leaving a negative ellipse with sharp borders.

S. Thompson and O. J. Lodge[‡] used Senarmont's method to verify the statement that linear conductivity depends upon the direction of flow along the line. They obtained the results they were looking for. The ellipses were elongated toward the analogous pole of the tourmaline (section cut parallel to *c*) with which they were working. The individual values for the ratios of this elongation varied from 1.17:1 to 1.42:1,—results varying so much as to be considered valueless by the writer. More accurate methods of other observers gave determinations of these values in which the maximum difference was under one per cent.; and we may yet be able to devise means sufficiently accurate to verify experimentally that heat flows with equal facility in either direction along a given line, regardless of pyroelectric or other properties. The only reason this matter is mentioned here[§] is to show what the personal equation can do in such a case, and within what extremely wide limits the results of good experimenters varied with this method. The last point will be brought up again in discussing the probable error of the results on the thermal conductivities of schists.

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[*] Liebisch. Physikalische Crystallographie. Veit & Co. Leipzig, 1891.

[†] W. C. Roentgen: Über eine Variation der Senarmont'schen Methode zur Bemessung der isothermen Flächen in Krystallen. Ann. Pogg. 151, 613, 1874.

W. C. Roentgen: Über eine Methode zur Erzeugung von Isothermen auf Krystallen. Zeit. f. Kryst. 3, p. 17, 1879.

[‡] On Unilateral Conductivity in Tourmaline Crystals. Phil. Mag. (5) 8, p. 18, 1879.

[§] The matter is discussed in some detail in Liebisch, loc. cit.

A fairly comprehensive list of ratios of thermal conductivities to the one-half power (this gives the ratios of the axes of the isothermal ellipsoids) is appended herewith for future reference. Many of these have been checked by measurements of absolute conductivities by the method of Forbes and in other ways.

For the monoclinic minerals, *c* will be replaced by "parallel to that axis of elasticity which lies nearest *c*"; and the fourth row shows by its sign in which quadrant this axis lies. The sign + indicates that it lies in the obtuse angle between the *c* axis and the clinodiagonal. The numbers show how far from the *c* axis this axis lies. The third column will still indicate values parallel to *b*.

Then the second column must indicate values along a line perpendicular to *b* and to the direction indicated in the first column.

The list includes no triclinic minerals.

		c	*a*	*b*	
ISOMETRIC	All minerals	1.00	1.00	1.00	
TETRAGONAL	Rutile	.79	1.00	1.00	
	Zircon	.90	1.00	1.00	
	Scapolite	.85	1.00	1.00	
	Vesuvianite	.95	1.00	1.00	
HEXAGONAL	Quartz	.76	1.00	1.00	
	Specularite	1.10	1.00	1.00	
	Dolomite	1.05	1.00	1.00	
	Apatite	.96	1.00	1.00	
	Tourmaline	1.15	1.00	1.00	
	Calcite	.91	1.00	1.00	
ORTHORHOMBIC	Barite	1.00	1.06	1.03	
	Anhydrite	1.00	.971	.943	
	Staurolite	1.00	.97	.901	
MONOCLINIC	Tremolite	1.00	.60	.75	— 5°
	Hornblende	1.00	.71	.80	
	Epidote	1.00	.93	1.09	—14°5
	Gypsum	1.00	.80	.65	+17°

METHODS USED BY THE WRITER.

The rock to be investigated was sawed or, where possible, broken with a hammer, in such a manner as to give it a face approximately parallel to the section wanted. This face was then ground smooth and true, and coated evenly with a thin layer of white wax.

The wax used had a melting point of 63.6°, as determined by the mercury bath method. Lower melting points, down to 38° C, can be secured at pleasure by adding turpentine in varying proportions. The wax was applied by dropping a few shavings of it onto the previously heated face of the rock, tilting the latter back and forth until a film of melted liquid covered the whole upper surface, pouring off the excess, and then allowing the whole to cool. The point of a hot copper wire was next placed perpendicularly upon the prepared surface. As the heat flowed outward radially from the point, a small, approximately elliptical, area of the rock face became heated above the melting point of the wax.

The area of the ellipse increased more and more slowly, until the integrated radiation and convection losses per unit time became equal to the rate of flow across the last section of the copper wire. The area of the growing ellipse will depend on the one hand upon the conductivity and the thermal capacity of the rock, and upon those properties of the surface which vary the surface losses; and on the other hand, upon the time, the temperature of the copper wire and of the air, and very largely indeed upon the temperature of the rock. Other causes affect it to an inconsiderable extent.

The melted wax is drawn outward by its surface tension, and, the point *a* being removed, it cools as shown in section in fig. 1 (enlarged about 8 times). In this way, the 63.6° C. isotherm is permanently fixed and may then be discussed and measured at leisure. Usually 6 to 12 figures were thus fixed on the same rock face before any measurements were taken.

The apparatus used had to be so arranged that no radiant energy capable of vitiating the results could reach the rock surface. With this and several other ideas in mind, the following scheme was finally evolved, and was considered satisfactory. One end of a piece of No. 8 copper wire (diameter about 1/8 inch) was filed to a long point and the wire was bent into the shape shown in fig. 2. A hollow glass cone was then fitted around the point, and stuffed full of a pasty mixture of plaster of Paris and asbestos fibre. This dried firm. The Bunsen burner flame was applied at the point B. As a further precaution against radiation from the flame, a piece of 6″×6″ asbestos sheeting, with a one-inch hole in the center, was slipped around the glass cone from below until it was held safe by the friction. This was soon dispensed with as an unnecessary refinement.

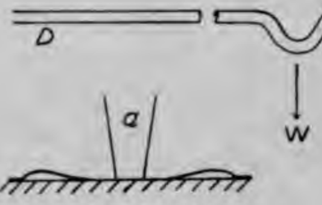

FIG. 1.

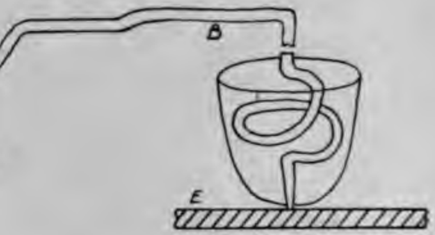

FIG. 2.

The apparatus, when in use, was clamped in a vise at D. The weight W was removed. The Bunsen burner was adjusted. The section E was placed, with the aid of ring-stand and clamp, directly underneath the point of the wire and about one-fourth inch from it; the prepared surface was then leveled so that it would be parallel with the plane surface at the end of the wire when the latter was lowered through the intervening one-fourth inch. This lowering was accomplished by replacing the weight W. On again removing the weight, the wire resumed its original position, the melted wax solidified, and the ring-stand was shifted so as to bring a new portion of the surface underneath the point of the wire. This cycle of operations was repeated until the entire surface was covered with wax figures. (See Plates 26 and 27.)

This method is simple, inexpensive, and, if used with care and a little skill, effective; moreover, it required but little apparatus which was not at hand either in the petrographical or in the physical laboratories.

A word as to the kind of point filed on the wire will not be amiss. At first it was the tip of a long cone, but no heat can flow across a point, and the tip of the cone had to come off. The question was how much of it, how large a section would give the best results. Without going into the details of differential heat equations, there are in general two limits to be discussed,—a very large section or a very small section. In the case of the latter (fig. 4), the only objection is that the heat which flows across can be dissipated from the surface of an ellipse which is very small indeed. In the case of the former (fig. 3), both x and y would be greater, but a good contact of the wire on the rock could hardly be expected. Figure 5 indicates roughly what might be obtained in the way of a contact, where the unshaded portion would show an air film between the copper wire and the rock. Then, too, a large section that is as nearly circular as it can readily be fashioned, would give appreciably different values for the diameter in different directions, and d_0 would not be a true constant. Another element which might be worth considering is that, in measuring many

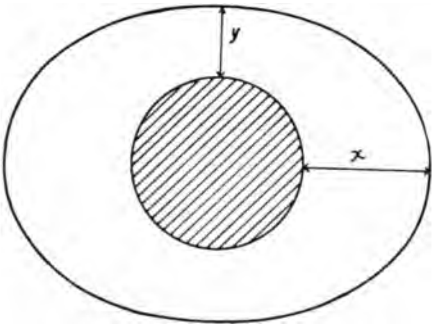

FIG. 3.

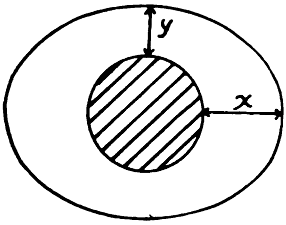

FIG. 4.

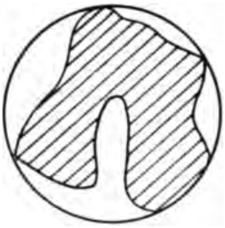

FIG. 5.

hundred ellipses, the time consumed in racking the microscope tube back and forth over a large dead area would be very considerable.

The cone was trimmed back three times in the early stages of the work, and was used for most of the tests with a diameter d_0=1.20 mm. The total diameters of the ellipses varied from 3.00—6.00 mm., most of them being very near 4.00 mm. The traveling microscope which was employed read distances to 1/400 mm. and throughout the work this smallest reading of the instrument was taken as unity. Thus the constant subtracted for d_0 was 480, since 480 (1/400 mm.)=1.2 mm.

Thus the ratio of two axes might be 1334/1673. From this, the corrected ratio is found to be (1334–480)/(1673–480), or .717.

To facilitate finding the limits of the wax figures under the microscope, it was found advisable to scratch a number into the wax on the inner flanks of the figure, and, in a few cases, to delimit the field by scratches, as in fig. 6. Oblique natural light was used. The shadows which it cast around the figure as a whole were of no value, but it brought out very clearly, by high lights, the extremely fine-grained, uniform texture of the twice melted wax, as compared with that which surrounded the figure and which had been melted but once. It was very easy, by observing this distinction, to follow the line of contact entirely around under the microscope, and any figure which showed irregularity in outline was rejected.

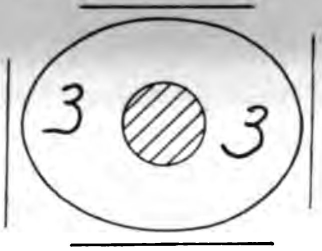

FIG. 6.

The ratios of the three axes of the triaxial ellipsoidal isotherms are uniquely determined by measurements in two properly chosen sections, but a third section of each rock was taken as a check.

For the purposes of demonstration, that is, to obtain wax figures which would stand out prominently, and which could easily be seen and photographed, numerous expedients were tried. Paris white and various Diamond Dyes were dissolved in the wax to give it body. Paraffin and beeswax were used. Nothing more satisfactory than white wax developed, and the pictures show that it was unnecessary to waste further time in experimenting along this direction. (See plates 26 and 27.)

THE CONVENTIONS USED IN SPEAKING OF THE SCHISTS.

For convenience of reference, the three axes will be denoted by *A, B*, and *C*, as in crystallography, the rocks being set up according to the following scheme. A plane parallel to that of the schistosity always contains *A* and *B*, and will be designated as the top face of the rock. If in this plane there exists also a linear orientation of the crystals, this direction is *A*, and is placed pointing directly away from the observer. If the schistosity, however, appears to be linear, only the *A* axis is fixed, and the choice of the top face is arbitrary until measurements on the face perpendicular to *A* give the direction of the major axis of the ellipse on this face. The direction of this major axis and that of the linear schistosity then determine the basal plane. If the schistosity is of two dimensions, but there is no linear orientation of the crystals, only the top face is determined, and, if the conductivity depended upon the structure, we would expect to find equal conductivity in all azimuths in this plane. Hence the directions of *A* and *B* become matters of indifference.

With our schists thus set up, we can imagine each rock cut into the shape of a rectangular parallelopipedon, with the pinacoids each containing two axes, and then we may use the terminology of the orthorhombic system, since all four rocks yielded heat conductivity ellipsoids which are analogous in every important respect to the light conductivity ellipsoids of the orthorhombic system,—the axes of elasticity are unequal, are rectangular and coincide in direction with the three rectangular crystallographic axes of symmetry.

We have then, in general, three sections to work upon: the top or basal pinacoidal face (containing *A* and *B*) shows the effect of the linear orientation; the end or macropinacoidal face (containing *B* and *C*) shows the effect of the schistosity; and the side or brachypinacoidal face (containing *A* and *C*) shows the effect of the schistosity superimposed upon that of the linear orientation. The two effects were found in all cases to be superimposed in the same sense,—to have the same sign. However, as the experiments indicate that the effect of structure in itself is zero this coincidence is an accidental one and is to be explained in terms of the thermal conductivities of the constituent minerals.

THE ROCKS INVESTIGATED AND THE RESULTS OBTAINED.

Four typical metamorphic schists were investigated. Each specimen which was used possessed to a remarkable degree uniformity of distribution of mineralogical constituents, and uniformity in the strong development of the schistosity. Each rock will be described in detail later.

At the temperature of the melting point of the wax (63.6°) C., the ratios of the three axes of the triaxial heat-conductivity ellipsoids were found to be as follows:

		(Observed.)		(Computed.)	
	A	*B*/*A*	*C*/*A*	*C*/*B*	*C*/*A*÷*B*/*A*
Hornblende schist	1.00	.942	.885	.961	.940
Glaucophane schist	1.00	.961	.743	.769	.773
Quartzose schist	**1.00**	**.906**	**.860**	**.947**	**.949**
Mica schist (Fort Wrangell).	1.00	.894	.715	.808	.800

The fifth column is the quotient of the third by the second and should equal the fourth column.

These results are the average values for a large number of observations, and a few words as to their probable accuracy are in place here. There is no doubt that each individual reading truly represents the length of that line, measured to 1/40 mm., for the method of checking results showed that the lengths were being measured accurately. The tube was racked across, readings were taken at A and B, fig. 7, and the screw was given an-

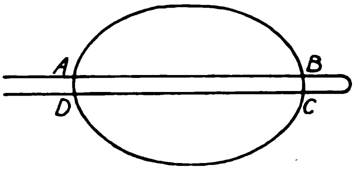

FIG. 7.

other turn. Then the motion was reversed. As the lost motion of the instrument was considerable, readings were obtained at C and D which were numerically different from those at A and B. If the two values of the differences of the readings agreed within ten units, as they easily did, no further measurements were taken on that axis.

It was found in the early stages of the work that the probable error of the mean of a number of observations on different figures on the same face could be kept under one per cent., without taking an unreasonably large number of readings,—not that the homogeneity of the rock was sufficient to give the same results on spots a few cm. apart, but the mean value represents the average ratio over a large portion of the specimen. One per cent., then, was set as the limit of the probable error of the mean value of any one ratio, and the number of readings was increased where necessary till this accuracy was obtained. Columns 4 and 5 of the table show that this intention was probably realized.

Senarmont, working with the largest obtainable monoclinic crystals, said: "Selten sind die drei Beobachtungen einer solchen Genauigkeit fähig dass sie einer numerischen Vergleich gestatten." But his material was not always satisfactory. With a good specimen of calcite, he obtained on one face ten values varying from 1.09 to 1.19. Such is about the range obtained in the most unfavorable cases by the writer. The end section of the Wrangell schist yielded 19 results varying in value from .773 to .892. The probable error of the mean, .808, computed by the familiar formula $l = .6745\sqrt{\frac{\Sigma d^2}{n\,(n-1)}}$ was .009. A rhombic section parallel to *A* of the same rock, yielded as the most favorable case, seven values ranging from .810 to .835, with a probable error of the mean, .823, of .002. Of course the term probable error is really a misnomer, for this is not a case of measuring the same quantity a number of times, since neither the homogeneity of the rock, as before suggested, nor its uniformity of structure, as will be shown later, are such as to lead one to expect the same ratios at all points of any one surface. (A fresh *crystal,* however, might be expected to do this.)

PETROGRAPHY OF THE SCHISTS.

The Hornblende Schist.—This rock comes from Yum-Yum Lake in the Rainy River District, Ontario, Canada. Under the microscope it was the only one of the four schists whose simplicity of structure was such as to enable a satisfactory deduction of heat-conductivity ratios from a knowledge of the structure, and of the thermal conductivities of the constituent minerals.

The rock is entirely crystalline. The structure corresponds to the allotriomorphic granular of igneous rocks. Foliated structure is well developed. Quartz (x) is the only mineral that shows the results of dynamic metamorphism well developed, and even here wavy extinction is not prevalent.

The constituent minerals are:—hornblende, quartz (x), quartz (y), orthoclase, acid plagioclase, epidote, titanite, apatite, magnetite, hematite.

The tendency toward idiomorphism of the constituent minerals decreases in the same order as in those igneous rocks in which the normal order of crystallization is followed. Thus in the order of strongly developed idiomorphism come (1) apatite, (2) magnetite, (3) titanite, (4) hornblende, (5) the others.

Three slides of the hornblende schist were made, parallel respectively to the bottom, side and end of the rock.

The hornblende makes up probably a good one-third of the rock as judged from the slides. The idiomorphic character is not very well marked. The prism faces and the clino-pinacoid are fairly well developed; in the case of the former, this may be due to the well-marked cleavage rather than to any strong idiomorphic tendency. The habit is elongated parallel to *c*. The pleochroism is very marked. The colors are: **a**—light brown or yellow; **b**—dark brownish black or greenish black; **c**—sea green (if very thin) to black. Absorption—$\mathfrak{b} = \mathfrak{c} > \mathfrak{a}$.

The hornblende shows a remarkable uniformity of crystallographic orientation. The parallelism of the longer axes could be seen macroscopically, and since the habit is elongated parallel to *c* in every case, all *c* axes are parallel. The bottom and side rock sections but rarely showed any prismatic cleavage.

The end section showed well developed prismatic cleavage in nearly every specimen. Here none of the minerals were cut even approximately parallel to *c*. The acute prismatic angle varied but little on either side of 56°. The longer diagonals of the cleavage parallelograms of the sections were roughly parallel to *b*. The uniformity of the orientation was not as marked as that of the *c* axes in the bottom or side sections of the rock, but it was strongly developed.

The orientation of those basal sections which were devoid of the traces of the prismatic cleavage was readily determined by the pleochroic colors. In fact, the whole scheme of orientation was first worked out independently by means of the pleochroism, then by means of the cleavage.

The arrangement of the other minerals follows no law. If the hornblende were eliminated from the rock, there would be no reason why the wax figures should vary from the circle. And the smoothness of the circle would be marked because, in general, the crystals are so small that their heterogeneously arranged variations in conductivity could not seriously affect the outline of the circle.

The relative thermal conductivities of the rock are very satisfactorily explained by taking account of the relative conductivities of the hornblende.

These are $1.00 : .\overline{71}^2 : .\overline{80}^2$.

The first number is for an axis which very nearly coincides with *c*; the third is for an axis parallel to *b*, and the second is perpendicular to these two.

If we assume one-third of the rock to be hornblende, or imagine the whole rock to be one large crystal of a hornblende in which the differences in thermal conductivities have been diminished by two-thirds, we would have a ratio of

$$1.00 : 1.00 — (1.00 — .\overline{71}^2)\ /3 : 1.00 — (1.00 — .\overline{80}^2)\ /3.$$

This yields a crude approximation to the values we should find. The ratio reduces to $1.00 : .\overline{914}^2 : .\overline{938}^2$. The rock shows a ratio of $1.00 : .\overline{885}^2 : .\overline{942}^2$ for directions which nearly coincide with those of the hypothetical hornblende crystal. The coincidences of the second members is not remarkable, but that of the third is. If this explanation is the correct one, then the thermal conductivity of this rock is very definitely merely the integrated effect of the thermal conductivities of its constituent minerals, and the structure *of itself* is of no consequence.

A brief description of the other constituent minerals of the rock is essential in order completely to individualize it.

Quartz (x) occurs in large lenses in large fragments. A cross section of these lenses may be as much as .2 by 3.0 cm. The individual fragments show no uniformity of orientation, and some of them show a greatest dimension of .3 cm. A wax figure that covered a part of such a large fragment would naturally be unsymmetrical. The non-uniformity of orientation of the fragments of these lenses is shown by the diagram fig. 8, the result of a few minutes of work with the quartz wedge. The interference color shows how nearly the axis of elasticity is perpendicular to the section, and the line shows the projection of this axis on the plane of the section.

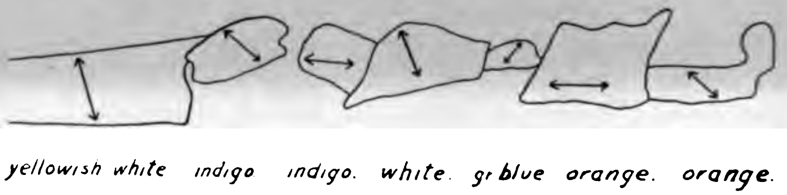

FIG. 8.

The quartz (y) and the feldspars give the rock its uniform allotriomorphic granular character. There is little variation in size of the grains. Albite twins are scarce but not rare. The extinction angles of the twins, measured from the traces of the planes of composition, are low. This latter fact and the uniform gray blue tints of the feldspars indicate the absence of any plagioclase more basic than oligoclase or andesine. If we remember that in non-igneous rocks the albite twins of the feldspars need not be well developed, we find it impossible to separate the feldspars into orthoclases and plagioclases. Quite a few carlsbad twins are present, however, and these tell us something.

The quartz makes up about ⅛ of this aggregate of feldspar and quartz. It is easily recognized by its yellow interference tints and such identifications are always corroborated by the characteristic undecomposed faces and by the Becke test.

The titanite is very uniformly and plentifully distributed in small rounded or rhombic shaped sections.

The epidote occurs in small fragments very sparingly distributed.

The apatite is very abundant in small idiomorphic crystals.

The magnetite is all in fairly large grains. One cross-section shows a maximum diameter of over 1 mm.

The hematite occurs in a few blood-red blotches.

Broad zones of strongly developed kaolinization permeate the rock. There are no fissures observable along these zones and the reason for their presence is not apparent.

The Glaucophane Schist.—This is a local schist from Berkeley. The rock is wholly crystalline. The structure corresponds to the allotriomorphic of the igneous rocks. Foliated structure is well developed. The constituent minerals are:—glaucophane, lawsonite, acid feldspars, and epidote.

Glaucophane makes up over 80 per cent of the rock. The habit is elongated parallel to *c*. **c**:*c* is less than 6 degrees. The optical orientation is very easily determined by the pleochroic colors. These are as follows: **c**—sky blue to ultramarine blue; **b**—reddish or bluish violet; **a**—yellowish to colorless (white).

The individual crystals are small. The bottom slide contains **c** of every crystal and **a** and **b**, or components of both promiscuously. Thus with the upper Nicol out, the tint of the rock as a whole varies uniformly as the field is rotated.

The side and end slides show a parallelism of the traces of the *c* axes, but the axis itself may lie in the plane of the slide or make any angle with it. Thus many sections show the prismatic cleavage, many sections contain **a** and **c**, many contain **b** and **c**.

The structure of the glaucophane in the rock is then apparently as follows:—all the longer axes (*c*) lie in planes parallel to the bottom of the rock; in each plane the *c* axes point in all azimuths indifferently. There is no uniformity of orientation of *a* and *b* whatever.

Then in the table on page 216 we would expect to find under the glaucophane schist that $B/A=1.00$, and that $C/A=C/B$. But B/A as measured on one face gives .961; and computed from the two other faces, $C/A \div C/B = B/A = .743/.769 = .966$.

The lawsonite in the rock may explain this discrepancy. This mineral makes up from 5 to 30 per cent of the rock. It gives the rock a tendency toward gneissic structure, some portions being almost free from it, others very largely composed of it. The rock slide parallel to the end shows elongated sections with both **c** and **b** parallel to the elongation, and also parallel to A. The side slide shows more nearly square sections; they are not as uniformly oriented, nor are they as numerous.

The base shows very much albite and all kinds of orientation of the lawsonite. Of the latter most sections are elongated, and **c** is always perpendicular to the elongation.

No data are available for the thermal conductivity of either glaucophane or lawsonite. If the glaucophane were the only constituent, we might work backward and get a general idea of the relative thermal conductivities of this mineral. As it is, the study of this rock is of no value for our work. However, it throws some further light on the structure of schists, and strengthens the idea that the structure of the rock in itself has no effect upon the elasticity of the ether in different directions, but that the thermal conductivity of the rock is the sum of the thermal conductivities of the constituent minerals.

The Quartzose Schist (Whetstone).—This rock is used as a whetstone. It comes from Telemarken, west of Laurdal, Norway. The constituent minerals are muscovite, quartz, calcite, magnetite, and biotite.

In the bottom and side slide the quartz appears in unelongated grains.* There is no uniform orientation, as is seen by all heights of interference colors, and all orientations of the axes of elasticity. The quartz nearly all shows a stepping of the colors with the Nicols crossed. This is due to the angular nature of the fragments. In addition to this evidence of hard usage, the quartz shows conditions of strain at present. It apparently makes up over 70 per cent of the rock.

In both of these sections the calcite appears in elongated rectangular sections parallel to the pencil structure of the rock, but making various extinction angles with this direction, as in fig. 9.

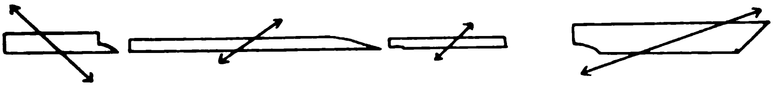

Fig. 9.

The muscovite is very abundant, filling in the spaces between the quartz. Some sections lie in the planes of these two slides, others are apparently on edge; still others occupy intermediate positions. These two sections would indicate the presence of 15 per cent of muscovite.

The end section presents an entirely different appearance. The quartz grains seem much more numerous and closely packed, none of them being masked by muscovite. The muscovite here appears as foliae interstitial between the quartz, and forming a network of red, green and violet "Fisseln," as seen under crossed Nicols. None of the characteristic elongated sections of calcite appear here.

Summary of the structure of this rock:

The muscovite occurs in minute flakes whose planes are always perpendicular to the end section of the rock. Without checking by chemical analysis and mindful of the deceptive masking power of muscovite, we may assume it to make up 6 to 8 per cent of the rock.

The quartz makes up 90 per cent of the rock and in those few sections which show one greater dimension of the fragments these are generally parallel to A of the rock. But this dimension has no relation to any axis of elasticity of the quartz.

The calcite occurs in pencil shaped forms with the ratio of dimensions about 4:1:1. All the long axes are parallel. It shows evidences of strain. It constitutes about 1 per cent of the rock.

A few flakes of biotite occur, also a few grains of magnetite.

A single case of polysynthetic albite twinning was observed.

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*Cf. Rosenbusch's Gesteinslehre, p. 501.

This rock is then again unsatisfactory for making numerical comparisons. One would from this expect the heat conductivity ellipsoids to be nearly spheres.

The Wrangell Mica Schist.—This rock comes from the Stickeen River District in Alaska. Large, perfect crystals of andradite* occur plentifully. The schistosity of the rock is due mainly to the uniformity of orientation of the mica plates. The fracture is roughly undulatory, not planar, and is good at as widely different directions as those represented by 11 and 12 of the figure. Almost any section perpendicular to *A* shows, when polished, beautiful mica spangles. Especially is this so of the bottom section.

Under the microscope it is seen that the micas lie with their basal planes within 15° on either side of *B*. Hence slide 14 and slide 10 (in the plane of the paper) show cleavage and pleochroism in most sections. The cleavages are parallel enough here to give the rock a uniform tint, and one which changes very decidedly as the stage is rotated; the pleochroism is very marked and the absorption strong. The pleochroic colors are dark red brown parallel to the cleavage and colorless to very pale grayish brown perpendicular to the cleavage. The basal sections show slight pleochroism. The extinction angle is uniformly very near zero. The mica makes up a large part of the rock.

Sillimanite is very plentiful in slides 14 and 12 as though its distribution were roughly planar also. The needles are so extremely fine that they defy detection, generally, if they occur in cross section. They occur in long attenuated crystals, often grouped radially. Their occurrence seems to be governed in some way by the presence of the micas. The index of refraction is very high, as compared to quartz by the Becke test, and the dark total reflection borders generally meet and mask the color. On some crystals, however, it can be seen that the color varies from colorless to a very definite pale green or bluish-green. A protracted search showed transverse cracks in only three of the needles. The birefringence is quite high, as even these fine needles affect the interference color of quartzes lying in the same vertical plane. The extension is positive.

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* Cf. analysis by A. S. Kuntze. Dana's System of Mineralogy, p. 444.

The quartz is very abundant. It occurs in small grains whose angular character is well brought out by the stepping of the interference colors. It is full of dark spots and fine inclusions. the latter largely apatite. Feldspars are very rare. A few orthoclases and acid plagioclases were found.

Apatite occurs plentifully, both as inclusions in quartz and as fairly large crystals between the quartzes.

The magnetite is very plentiful in small grains, usually associated with decomposed micas. Pyrite occurs irregularly. In a few places half of the field is pyrite. It seems here to be occupying the place of micas too, though the latter contain no sulphur. Hematite and titanite occur rarely. A few large sections of clinochlore were found.

The axes of the wax figures gave results of 1.000: .894: .715. It is manifestly impossible to tie these results down numerically to the known thermal conductivities of the constituent minerals. The undulatory fracture indicates that no results of any value for our work can be obtained. The presence of small garnets and local impoverishments due to their formation points in the same direction. The numerical results checked more poorly than for any other rock, necessitating the reading of several dozen ellipses on one face to get the probable error. Thus (fig. 10) readings on the face *y* reduced to 100: 79.7 for *A* : *y*; and on the face *x* reduced to 100: 86.9 for *A* : *x*. But on the face perpendicular to *A* the values were 100: 80.8 for *B*: *C*. If we construct an

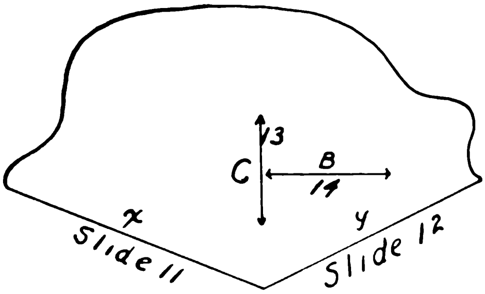

FIG. 10.

ellipse with major and minor axes 100 and 80.8 and take $B:y=30°$ and $B:x=20°$, the equation of the ellipse gives us that

$$\left(\frac{79.7\ K \cos 30°}{100}\right)^2+\left(\frac{79.7\ K \sin 30°}{80.8}\right)^2=1$$

and

$$\left(\frac{86.9\ K \cos 20°}{100}\right)^2+\left(\frac{86.9\ K \sin 20°}{80.8}\right)^2=1$$

K is the same in both equations. Solving the first equation we get $K=1.18$. Solving the second equation we get $K=1.12$. The two values do not check satisfactorily, and emphasize the conclusion arrived at from a miscroscopic study of the rock structure, namely, that it is wiser not to draw any conclusions from the study of this specimen.

University of California,
May, 1905.

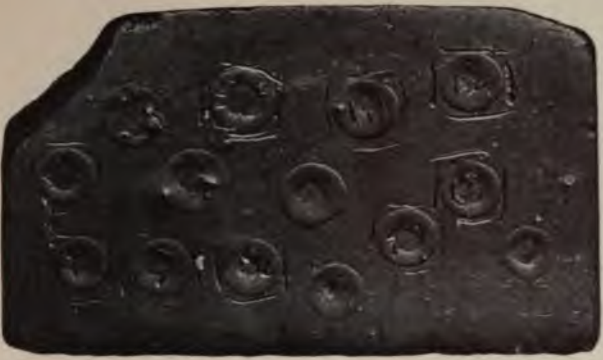

FIG. 1.
Hornblende schist from Yum-Yum Lake, Canada. End section.

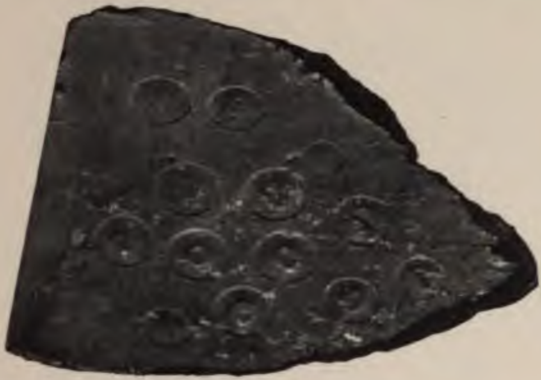

FIG. 2.
Glaucophane schist from Berkeley. End section.

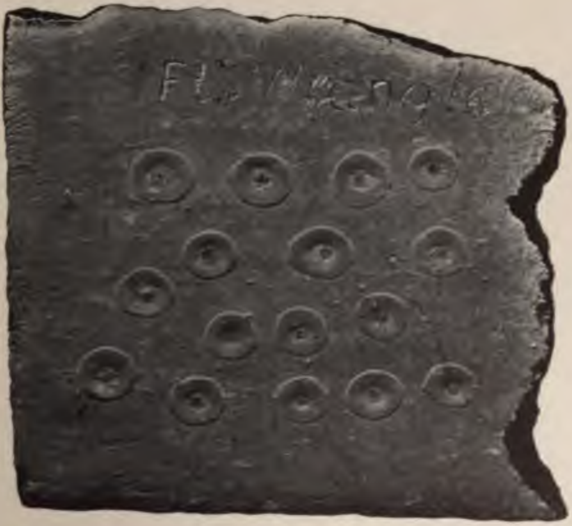

FIG. 3.
Fort Wrangell mica schist. Parallel to *A* (*y* of text fig. 10).

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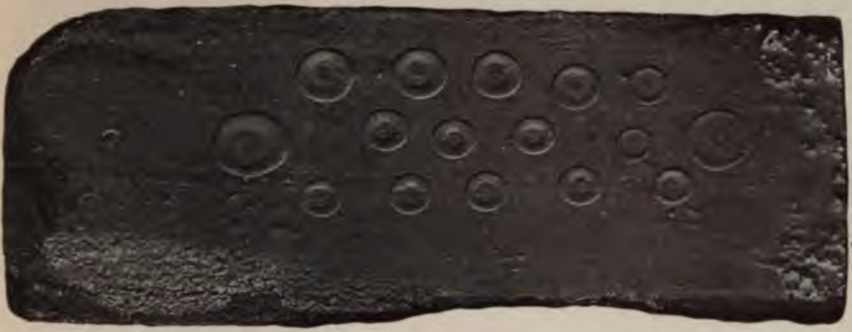

FIG. 1.
Hornblende schist from Yum-Yum Lake, Canada. Side section.

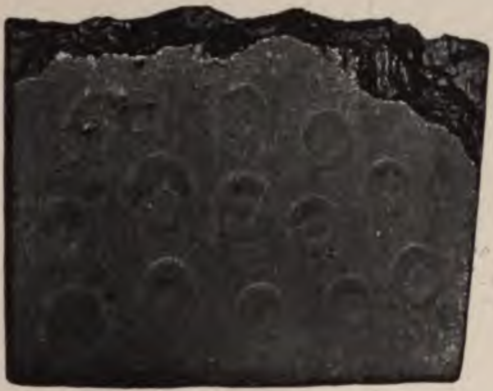

FIG. 2.
Quartz schist. Laurdal, Norway. Bottom section.

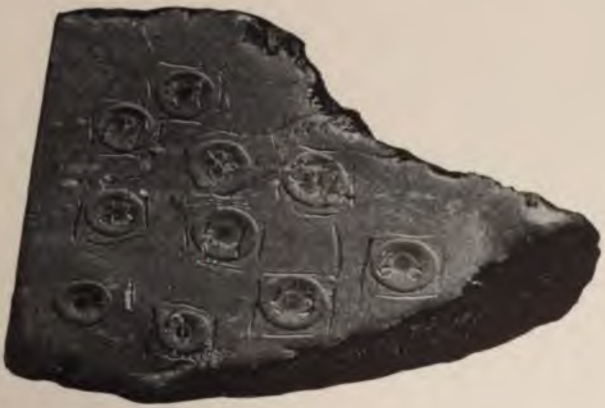

FIG. 3.
Glaucophane schist from Berkeley. Side section.

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SKETCH OF THE GEOLOGY OF MINERAL KING, CALIFORNIA

BY

A. KNOPF AND P. THELEN

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INTRODUCTION.

Mineral King is situated on the headwaters of the East Fork of the Kaweah River near the western crest of the southern Sierra Nevada. This portion of the range is known as the High Sierra, and is preëminently distinguished by the sharply serrate character of its profiles and the vast assemblage of lofty peaks.

Of these none illustrate more impressively the peculiar felicity of the term "Sierra Nevada" than does Sawtooth, under whose shadow Mineral King lies. Mineral King occupies very nearly the north center of a narrow belt of sedimentary rocks, now more or less schistose, some 14 miles long and 2 miles wide, and striking N.N.W. This area of stratified rocks represents an isolated remnant of the extensive terrane into which the Sierran batholithic magmas were intrusive during Mesozoic time. The hypsometric relations disclose the fact that the schists are deeply sunk into the granites, and make it obvious that their preservation is in large part due to this favoring circumstance. The belt has been strongly mineralized, whence its name, and has invited a large amount of prospecting, but exploitation has not proved profitable. The region was traversed by Professor Lawson in his physiographic reconnaissance of the upper Kern Basin, and its salient features outlined and discussed in concise form. It was suggested by him to the writers as an interesting field for more detailed study, especially in regard to its contact phenomena and its stratigraphy. We wish here to express our sincerest acknowledgments of his ever ready help and encouragement.

GEOMORPHY.

The portion of the region with which we are here concerned cannot be said to constitute a geomorphic unit. In its longitudinal extent it embraces a linear succession of strike valleys, whose profiles show the glacial U-shape in splendid development. The tributary streams, heading invariably in rock-rimmed lakelets, drain across the upturned edges of the strata, and enter the main valleys by series of waterfalls, often several hundred feet high. This lack of adjustment between master stream and lateral drainage is particularly well exemplified by the valley in which Mineral King is situated. This valley is broad and flat-bottomed in its lower extremity, its walls are sheer, and have shed sufficient talus to yield a U-profile of ideal perfection. The floor of the valley is built up of glacial debris, through which the stream meanders in short tortuous curves, at an average grade of a hundred feet to the mile. Just below

Mineral King, the Kaweah suddenly swings through 90° and commences its rapid descent down the western flank of the Sierra Nevada at a rate exceeding 600 .feet per mile. These various physiographic features are readily discernible upon the contour sheet, and hardly need comment.

The relief of the region is exceedingly bold and rugged, varying from a maximum of 12,405 on Florence Peak to 6,500 feet on Cliff Creek, or over a mile in altitude. The crest lines are fierce and jagged, and consist characteristically of huge angular spauls of rock recumbent in various unstable attitudes, like a chaos wrought by the play of titanic forces. They are impressive evidence of the vigor and destructive intensity with which weathering progresses on alpine heights. Products of secular decay are nowhere present.

Great talus heaps mantle the bases of the cliffs. These accumulations vary in character with the lithologic habits of the parent cliff: the schists, quartzites and plutonic intrusives yield irregular confused aggregates of large angular blocks of widely varying sizes; the clay slates, on the other hand, encumber enormous slopes with fresh and unaltered debris which is uniformly of the size of a fist.

Occasionally deep sand slopes are developed. The production of these within this area seems to be determined by petrographical influences. The sand consists of the loose accumulation of fragments of disintegrated granite, often up to the size of a walnut, and grains of quartz and feldspar which still preserve their pristine freshness.

Characteristic accumulations occur at Sawtooth Peak, where the granite possesses a striking individuality. This granite is a coarsely granular aggregate of quartz and orthoclase, with very small amounts of hornblende and biotite. The quartz occurs typically as anhedrons of the size of peas uniformly scattered throughout the rock. The sand slopes are limited to this particular variety of granite, and it is significant in this connection, that the quartz-mica-diorites, which are rocks of firm and closely coherent texture, do not yield sands under the same conditions, but produce great talus heaps.

On the granites west of Vandever Mt. is a plateau surface whose profile against the sky line shows smoothly flowing lineaments, and which represents the nearly obliterated remnants of an earlier geomorphic cycle.

GLACIATION.

Evolution of the Topography.—The region bears abundant evidence of a former severe alpine glaciation, which, nevertheless, must be regarded as having been of comparatively limited duration. There is a general absence of well-defined terminal moraines. A heavy deposit of lateral morainic material flanks the west wall of Mineral King valley some 800 feet above its floor. Half a mile below Mineral King striations show that the glacier was not less than 1,000 feet thick. At the confluence of Deer and Cliff Creeks is a great medial moraine consisting almost wholly of angular blocks of quartz diorite, which has shifted the junction of the tributary considerably down stream along Cliff Creek. The evidence from the character of the morainic material indicates that the tributary glacier, having but a feeble catchment area, receded before the main glacier of Cliff Creek commenced to wane, which then dammed up the mouth of its affluent. Toward the head of Cliff Creek not more than a quarter of a mile from the cirque a low embankment of loose angular blocks spans the cañon from wall to wall. This is the only typical terminal moraine occurring within the confines of the region under discussion.

The extreme recency of the disappearance of glacial conditions is shown by the preservation of highly polished surfaces upon exposed granites, and of groovings and striations upon soft schists, and perhaps still more emphatically, by the insignificant amount of post-glacial stream erosion. This latter has limited itself to a slight notching of the cañon bottoms, but has not yet advanced far enough to remove the veneer of glacial material from the floor of Mineral King valley.

The glaciation has left its profound impress upon the geomorphic configuration of the region: in the production of numerous amphitheatres and encircling arrêtes; in the formation of strings of rock-rimmed lakelets, and in the development of splendid U-shaped valleys. The ideal character of the U-profile of the main valleys—Cliff, Mineral King and Little Kern, has been alluded to and the strong discordance between lateral and main drainage pointed out. This lack of stream adjustment is all the more remarkable when considered in the light of the Pleistocene history of the range. The post-Pliocene uplift tilted the Sierra Nevada orographic block to the west, the upheaval in this portion of the range being not less than 10,000 feet, and has thereby enormously accentuated the grade of the westward-flowing streams. The drainage is still in the early consequent stage, and the trunk streams have, in other portions of the range, cut below their meridional tributaries and left them hung up. At Mineral King, however, the orientation of the hanging valleys is irregular and unsystematic. Deer Creek—a strike stream eroding on clay slates and flowing north—is in poor adjustment to Cliff Creek, a stream flowing westward on granites. The streams heading respectively in Monarch, Crystal and Silver Lakes, and plunging down to the Kaweah at an average rate of 1,800 feet to the mile across the upturned edges of the schists, afford strong examples of hanging valleys. The two tributaries from the western side of the valley of Mineral King have not yet succeeded in even gashing its wall. The valley in these discordant relations to its lateral feeders is a strike valley for the greater part of its length. Above its abrupt bend to the west, it can be divided into two approximately equal portions, a lower portion, which is veneered with glacial debris, broad, flat-bottomed and of remarkable easy grade in spite of its high altitude (7,800 feet); and an upper portion extending to Farewell Gap, incised by post-glacial erosion, steeply graded, but showing to some extent the step-like progression characteristic of the lateral valleys. The transition between the two portions is relatively abrupt, and is coincident with the entrance of two lateral hanging valleys—Silver Lake on the eastern side, and White Chief on the western. Below Mineral King the valley cuts across the slates and schists into the granite, but does not change its essential character, except that it becomes broader.

Below the lower limit of glaciation—the 7,000-foot contour—it assumes a strongly consequent character, becoming V-shaped and taking on a grade of 500 feet to the mile. It is therefore evident, as an observational fact, that a valley of strongly marked individuality has been carved out coincident with the length of the ice stream, and that its evolution has been independent of lithologic control, inasmuch as its distinctive features are found equally well developed in firm unweathered granite, and across the strike of slates as well as along their upturned edges.

The Little Kern River is bordered by high hanging valleys in its upper region, but immediately below the lower limit of glaciation, the lateral streams are in complete accordance, notably the Shotgun and the Rifle. To sum up, the hanging valleys do not show any systematic arrangement such as would be produced by selective or differential erosion, or by faulting, but are inseparably associated with the evidences of glacial occupation.

The lateral valleys consist of a series of irregular steps, the successive treads of which are usually occupied by rock-rimmed lakelets. These lakes do not owe their origin to morainal dams, but fill basins eroded out of the solid granite. Their depth is small, perhaps never exceeding 30 feet. Some few have become silted up, giving rise to beautiful parks through which the mountain streams wind leisurely. The uppermost lake always occupies the circular basin of the amphitheatre at the crest of the range; the succeeding lakes are separated by differences in altitude of several hundred feet, and are invariably situated at the foot of the abrupt changes of elevation. The tarns are not confined exclusively to the granitic rocks, but occur also upon the sedimentary rocks.

In a number of instances cirques have been evolved partly in granite and partly in the sedimentary series, notably at Monarch Lakes, Crystal Lake, Silver Lake, the lakes S.W. of Florence Peak, White Chief and at Eagle Lake, and it is a noteworthy fact that in each case the symmetry of the amphitheatre has in no way been impaired or diminished. (See Plate 28.) A curious feature, whose significance is not entirely plain, is the tendency of the lakelets near the head of any lateral valley to associate in pairs, of which the lower is the complete analogue of the upper; see especially Monarch and Florence Lakes.

Evidence as to Mechanics of Glacial Erosion.—The tributary glaciers have not evolved the perfect U-profiles so characteristic of the main drainage lines, but are more of the nature of broad and relatively shallow troughs. The troughs upon the western flank of Mineral King are flat-bottomed, of few steps of long tread, and of nearly horizontal floor. On the eastern side the treads are shorter and more numerous, and the floor less regular and often approximating a V-shape. This V is not of post-glacial origin, but is grooved and striated in its upper portion, thus testifying to the efficiency of the subglacial streams. Everywhere are abundant evidences of the extreme recency of the glacial evacuation of the region. It is as if the ice had ceased its activity yesterday, and had left incomplete the work it had inaugurated.

The lateral valleys, particularly that of Monarch Creek, illustrate in no uncertain way the mechanics of the processes concerned in their evolution. The sides of the valleys consist of an ascending series of stopes, like the benches of a quarry, spreading laterally from the stream course as a medial line. The regularity and persistence of this phenomenon is closely dependent upon the perfection of the jointages, and is often truly remarkable. The jointage to which the bed of the creek is parallel controls the front face of the stopes, while a second jointage intersecting the former at an angle near 90° determines the floor. The salient angle thus formed has been rounded off to a slight extent, but upon the front face of the stope may still be seen partially obliterated inequalities of surface. These are jagged and angular in their innermost recesses and represent uneven fracture planes of the rock masses torn out by the ice from their positions. The front face of the stopes is nearly vertical and may have a height of from six to eight feet, and occasionally even up to fifteen feet. The rocks of Monarch Creek are of stratified character, but similar bench-like forms have been produced on the jointed granites at Silver Lake, and it is obviously apparent that the phenomenon is independent of lithologic control.

That the term "quarrying" is no mere figure of speech is forcibly brought home by the photograph shown in Plate 29B. This was taken on Crystal Creek at an altitude of 10,000 feet in a valley hung up 2,000 feet above Mineral King. No less than five benches are shown, scarcely distinguishable in their perfection from the labored handiwork of man. They are quarried out of a strongly sheared andesite in steps up to fifteen feet high, and display the efficient utilization of the two dominant jointages. The ineffectiveness of glacial abrasion compared to the process of plucking is also clearly revealed.

It has been mentioned that on Monarch Creek along with the numerous quarry-like benches evidences of a glacially striated notch occur in the bottom of the trough. Similar subglacial channels are reported from the Unter Grindelwald glacier and from the Yosemite Valley, and are held to furnish proof of the feebleness of glacial erosion. At Monarch Creek, however, the evidence is clear that the subglacial notch was an active coöperant with the glacial processes. The heavy grade of the stream limited its energies to the downward corrasion of its bed, and caused the incision on the floor of the valley of a narrow channel. To the ice was left the quantitatively much greater task of excavating the main trough and maintaining the typical character of the U-profile. It is a well-known principle to the quarryman that the facility with which large blocks can be removed is greatly increased by the number of free faces exposed to attack. The downward channeling action of the subglacial stream, therefore, afforded a vantage line for the quarrying ability of the ice, and has enabled it, by utilizing the latent free faces—the jointage planes,—to evolve the characteristic bench-like forms.

THE GRANITIC AND ASSOCIATED IGNEOUS ROCKS.

The Granitic Rocks.—The granitic rocks of the region comprise several strongly marked types, and represent somewhat widely divergent products of the same irruptive magma. While often maintaining their persistence of character over several square miles, a gradual transition through the medium of intermediate types frequently takes place. The prevailing rock upon the eastern flank of the belt is a very coarsely granular aggregate of orthoclase and quartz with subsidiary amounts of biotite and hornblende. This granite readily becomes incoherent, and disintegrates rapidly, forming great sand-slopes. The microscope shows that the dominant potash feldspar is microcline, usually to the almost complete exclusion of the orthoclase. Associated with these are small amounts of acid plagioclase, and occasionally, microperthite and microcline-microperthite. Besides the usual accessories, magnetite, apatite, titanite and zircon, the quartz is noted to contain capillary rutile. This acid potash granite is splendidly exposed at Sawtooth Peak, at Silver Lakes and at Florence Lakes, and reappears on Shotgun Creek.

Passing south, the ferromagnesian minerals become more abundant, and the amount of plagioclase increases. Toward the southern extremity, the granite becomes noteworthy through the development of large, imperfect phenocrysts of orthoclase scattered somewhat sporadically throughout the matrix. They often attain large dimensions, frequently measuring over four centimeters in length and are broad in proportion. The ground is a medium grained, eugranitic assemblage of orthoclase, plagioclase, quartz and biotite. The feldspars occur in nearly equal proportions, placing the rock among the orthoclase-plagioclase rocks as a porphyritic quartz monzonite.

West of Mineral King the granite is prevailingly of the hornblende-biotite variety. The rock is a typical orthoclase granite carrying a notable quantity of dark constituents. Toward the north, however, an interesting modification is met with. The granite becomes surcharged with lustrous black hornblende prisms, strongly idiomorphic, and frequently attaining a length of two centimeters. Splendent foils of biotite become conspicuous; sphene is macroscopically abundant, and quartz sinks to minor importance. Systematic collection of hand specimens along a normal to the contact showed a loss of the porphyritic habit with proximity to the sedimentary mass. The hornblende resumed the ordinary hypidiomorphic form, the quartz content was noted to increase, and at the contact the rock had become a quartzose granitite, barren of hornblende. Yet observation showed that most frequently this particular variety of granite would preserve its porphyritic habit to within two feet of the contact, where it would become obliterated, and a slight enrichment in the biotite content take place at the expense of the hornblende. This tendency toward the formation of a narrow peripheral zone relatively richer in biotite can macroscopically be seen to have been operative at numerous points, and even appears from microscopic evidence to have been effective in the leucocratic granites upon the eastern side of the area.

Inclusions in the Granites.—Dark circular and irregular oval patches, varying in size from half a square inch to a square yard, are exceedingly abundant in the granites of the region. They are resistant to atmospheric agencies and weather out in relief. Their outlines are sharp and distinct, though in detail interlocking with the grain of their hosts. The term "*schliere*" when applied to these is a misnomer. On the basis of textural differences, two classes can be recognized: the first of which is accurately described as a pepper-and-salt mixture of the dark and light colored constituents; the second type is a dark colored, medium granular aggregate in which occasional porphyritic feldspars are included.

The distribution of these two varieties of inclusions is not limited to any particular facies of granite, and is in general fairly uniform throughout the region. Over wide areas a common perpendicular orientation of the major axes is often observable though the porphyritic hornblendes of the enclosing rock are without definite disposition, either fluidal or gravitational.

At Eagle Lake, the glaciation has laid bare a truly remarkable phenomenon. Here the granite abuts against a white, schistose quartzite, which thermal metamorphism has rendered massive and vitreous over a breadth of a few inches from the irruptive. Paralleling the contact, and forming a zone in the granite from three to four feet wide, is an enormous assemblage of dark-colored ellipsoidal enclosures, so numerous as to constitute more than one-half the bulk of the rock. The contact is exposed to a vertical height of 20 feet at points, and horizontally, several hundred feet, and the inclusions are seen to have subordinated the granite to the function of a mere binding material. They have been oriented parallel to the plane of the contact, and show distinct evidences of plastic deformation, being somewhat flattened in the direction of their major axes. Texturally they are fine grained aggregates of the dark and light constituents. In thin section it is seen that the ferromagnesian minerals, represented by biotite, hornblende and augite, comprise half or more of the bulk of the slide. The biotite exceeds slightly the hornblende plus the augite. The hornblende, which is of the common green variety and strongly pleochroic, is frequently irregularly intergrown with pale green augite with the *c* axes common. The feldspars present are orthoclase and calcic oligoclase, associated together in nearly equal proportions. Quartz is very subordinate; a small but variable amount of micrographic (myrmectic) intergrowth is recognizable. The most noteworthy feature, however, is an extraordinary abundance of perfect apatite needles, often of long slender, acicular habit, with a length exceeding fifty times the breadth. Such needles must furnish sensitive indicators of any internal movements since the consolidation of the magma. The apatite is perhaps four or five times as plentiful as in its granite host. Zircon, titanite, pyrite and magnetite are sparingly represented. The structure is allotriomorphic granular, though occasionally the biotite shows sharp idiomorphism.

The host is a fairly coarse grained quartzose granite carrying a great deal of biotite and considerable hornblende. The foliae of biotite show an incipient effort to congregate, and give the granite a faint appearance of inhomogeneity. The microscope shows that orthoclase is the dominant feldspar, and that but a very small amount of acid plagioclase is associated with it. Apatite (somewhat more abundant than in normal granites), zircon, magnetite, and titanite comprise the accessories.

Throughout the hand-specimen can be observed small dark-colored patches, approximately half an inch square, which are pepper-and-salt aggregates of ferromagnesian minerals and white. In thin section, the patches consist of panidiomorphic equidimensioned aggregates of the above minerals with the dark equaling the white. It is noted, however, that the triclinic feldspars have become relatively more abundant, and that a notable concentration of apatite has taken place. Each little patch is apparently an integral unit which does not blend into the enclosing rock, though the line of demarcation is not absolutely precise, and shows sympathy with the grain of the host.

At seventeen feet from the contact, the granite does not differ essentially from that at but one foot, except, perhaps, in having recovered completely its appearance of homogeneity.

From Cliff Creek was obtained a dark medium grained granular inclusion, throughout which a few porphyritic feldspars are scattered. The host, which was not in any near proximity to the contact, is a hornblende biotite granite, conspicuous by the porphyritic development of the hornblende and the macroscopic character of the titanite. Under the microscope the inclusion appears to consist of biotite and green hornblende in equal proportions, oligoclase and the accessories. Quartz is insignificant or absent. The feldspar is characterized by having a core, or more frequently, a zone of sharp crystallographic habit consisting of kaolinized feldspar succeeded by a peripheral growth without exterior crystal outline. By far the most striking feature revealed in thin section is the extraordinary concentration of the accessories. Sphene is very abundant in sharp idiomorphic rhombs. In one instance an included cube of magnetite was noted, and in another, a small striated feldspar lath. A hornblende cross-section was found in parallel intergrowth with a titanite rhomb along their respective cleavage lines. Apatite displays a profuse development of long slender needles and short stout prisms. It is sometimes included in the sphene, and may occasionally be seen jutting into the titanite rhombs. Octahedra of magnetite are unusually plentiful. Zircon, however, is present in no more than normal amount. The structure is hypidiomorphic granular.

The peculiar mode of occurrence of the enclosures at Eagle Lake, and their great numerical abundance, seem to give the contact some significance in their genesis. At first sight, it would appear probable that here they represented partially digested fragments of the invaded formations, but the microscopic diagnosis, and the absence of the pronounced endomorphism which the assimilation of such large amounts of silica would necessitate, argue strongly against such an hypothesis. And furthermore, the deformation of the enclosures visible macroscopically should show corresponding structures microscopically. If the inclusions are of extraneous origin, and have suffered magmatic corrosion and plastic deformation, the individual mineral components should accordingly show incipient fusion. The deformation has necessarily been plastic, inasmuch as the drawn-out inclusions are contained in an unsheared granite as host. The thin section, however, reveals no evidence of incipient fusion, and shows that the various minerals possess the sharp, pyrogenic outlines characteristic of granular plutonic rocks. In reviewing the petrographic details it is apparent that the inclusions represent basic segregations from the granitic magma and are characterized by high concentrations of the so-called usual accessories. A close sympathy between host and segregation is indicated by the dominance of a peculiar accessory: apatite, in the apatite-rich granites and titanite in the titanite-rich granites.

Later Intrusives.—Intrusive into the schists and granite on Monarch Creek is a quartz-mica-diorite, which, wherever exposed, exhibits a uniform and persistent petrographic habit. The contact with the granite is marked by an irregular intrusion breccia, wherein the invading magma has incorporated numerous angular blocks of granite. Occasionally a light colored aureole three-quarters of an inch broad has been developed around the acid inclusions. Other evidence indicative of the irruptive nature of the quartz-mica-diorite is furnished by the frequent appearance at the contact of porphyritic facies resembling coarse, holocrystalline andesites.

Macroscopically, the quartz-mica-diorite is a medium grained granular rock, the tabular character of whose plagioclase feldspars is often apparent, even textured, and of gray color. Its weathered surface is characteristically of blue gray tint, and usually pitted, due to the atmospheric removal of the hornblende. Under the microscope it is seen that the total ferromagnesian content is relatively small and comprises biotite and hornblende, the mica commonly predominating. Plagioclase is present in large amount and is noteworthy from the strong tendency it displays to assert its idiomorphism. Its habit is tabular, and the feldspars almost invariably consist of Carlsbad twins striated according to the albite law. An accurate determination is therefore readily possible, and shows that the feldspar corresponds to andesine Ab_5An_3. A variable amount of orthoclase occurs, though usually in strict subordination to the soda-lime-feldspar. It is always allotriomorphic, and occasionally twinned according to the Carlsbad law. Strain shadows are observable, sometimes culminating in a microcline structure. A not inconsiderable amount of quartz is distributed throughout the body of rock so as to form an irregular mesostasis in which the tabular feldspars lie embedded. It is probably owing to this interstitial character that the quartz owes its macroscopic inconspicuousness. A few minute occurrences of graphic intergrowths were observed. The accessories are magnetite, titanite, zircon, and apatite somewhat abundantly.

The characterization of this rock shows that it is closely allied to the granodiorites, in the sense in which the term granodiorite has been most frequently employed ("quartz-mica-diorite carrying orthoclase"). It also accords exactly with the tonalite of vom Rath, to which, in the nomenclature of Rosenbusch, it would unhesitatingly be placed. The dark colored segregations so common in the granites are conspicuously absent in the tonalite.

Closely resembling the tonalite of Monarch Creek is a body of granite apparently intrusive into the hornblende granitite on the Wet Meadows trail. More careful inspection shows that the feldspars are largely unstriated and that the macroscopic resemblance is misleading and merely fortuitous. Under the microscope it is observed that plagioclase is not abundant, and that the potash feldspar is to a great extent intergrown with albite in microperthitic fashion. Quartz is unexpectedly present in no inconsiderable amount, though relegated to interstitial habit. The ferromagnesian minerals are sparingly represented by biotite.

Tourmaline Granite and Andesitic Dykes.—Cutting this granite at various places are intrusive masses of tourmaline granite and dykes of feldspar porphyrites. The tourmaline is quite abundant in the shape of radial aggregates, averaging a centimeter in diameter. A little plagioclase, orthoclase and quartz form a rather fine grained ground throughout which the tourmaline is distributed. The tourmaline spherulites are often located in the center of areas of quartz of uniform optical orientation. The porphyrites are characterized by an abundance of white feldspar phenocrysts embedded in a dark gray-blue ground of fine texture. Some biotite is noticeable, but is not conspicuous. In thin section the large feldspars display decided corrosion phenomena, having had all the corners rounded off. They correspond in composition to a calcic oligoclase. A not very prolific generation of much smaller plagioclase lathes succeeded them. They show no evidence of magmatic resorption, and are not connected with the first generation by intermediate sized feldspars. Some basaltic hornblende, for the most part strongly chloritized, and biotite represent the ferromagnesian minerals. Magnetite and apatite constitute the accessories. The groundmass, in which a little accessory quartz was noted, is holocrystalline and contains a great deal of chloritic matter scattered throughout it. The microscopic diagnosis shows, therefore that the porphyrites should more accurately be called andesites.

The detailed petrography of the granitic rocks of the region shows that in this portion of the Sierra Nevada there exist large bodies of typical orthoclase granites, and even highly acid potash granites. The time relations between the tonalite (grano-diorite) and granite magmas show that here the more acid preceded the less acid (tonalite) intrusion.

THE STRATIFIED ROCKS.

General Relations.—The stratified rocks consist prevailingly of clay slates and phyllites with interbedded limestones, quartzites, and large masses of tuffs and sheared volcanics, both acid and more basic. Superficial oxidation has colored the series a strong red and causes them to stand out in pronounced contrast to the gleaming white granites.

The strike of the strata is fairly uniform throughout the area, and does not vary greatly from N. 45° W. The dip is nearly vertical, usually 85° to the southwest. The bedding is in all cases found to be strictly conformable. At Mineral King the series attains a maximum width of 12,000 feet. South of Farewell Gap it narrows down to 5,600 feet. (See Plate 30.)

The rocks have been sheared to greater or less extent and exhibit various degrees of schistosity, from perfectly massive quartzites to highly micaceous biotite schists. The interbedded limestone beds show that the foliation is always coincident with the original stratification planes. This is further borne out by the thin sections, which frequently show the parallelism between the sedimentary banding and the superimposed cleavage.

The lithologic units are relatively small, and it was found inadvisable to attempt to map them separately. The siliceous, calcareous and argillaceous members are frequently stratified in rapid alternation, and, as a further complication, even the larger subdivisions are of strongly interdigitating habit and tend to thin out in the direction of their strike. The volcanic rocks, which constitute a large portion of the geologic series, are as a general rule conformable in strike and dip with the sedimentary rocks. They are strongly sheared, and have been invaded by the granites and are, therefore, certainly pre-granitic. Associated in conformable sequence with the quartz porphyries on the Little Kern River are beds of tuffs, and the evidence is clear that there the volcanics form an integral portion of the stratigraphic column. At other points different evidence is obtainable. On Monarch Creek dykes of dark igneous rocks are intrusive into quartzites and are themselves cut by white aphanitic dykes which are apparently apophysal from the tonalite intrusive.

Owing to the nearly complete absence of fossil content, the unreliableness of intercalated volcanics as data planes and the lenticular habit of the stratified rocks, correlations between various cross-sections can only be made in general terms. Where thicknesses are given, it must be borne in mind that their accuracy is conditional upon the accessibility or inaccessibility of the territory.

Section across Timber Gap.—A section along the ridge at Timber Gap reveals the following succession passing from west to east:

1.	Various facies quartz porphyry	500 ft.
2.	Banded red and white quartzite	150
3.	White and gray laminated limestone	50
	(The two feet adjacent to the next following formation are highly contorted and the laminae are often reversed.)	
4.	Phyllitic schist	50
5.	Arenaceous slates, siliceous schists and clay slates	300
6.	Phyllites and clay slates	800
	(Contains a 2-foot bed friction breccia.)	
7.	Siliceous schists, with subordinate schistose quartzites interbedded; thin bands clay slates	350
8.	Sheared conglomerate, tuffaceous	200
9.	A few feet phyllite, tuffaceous slate and green schist with cherty layers	750
10.	Clay slates	35
11.	Tuff	175
12.	Calcareous quartzite, occasional limestone lenses	180
13.	Clay slates	300
14.	Schistose white quartzite	50
	(Contains 4-foot bed blue limestone.)	
15.	Sericitic quartz porphyries	400
16.	Blue gray quartzites	500
17.	Sericitic quartz porphyries	350
18.	Quartzite	50
19.	Sheared feldspar porphyry	800
	Total thickness exposed	6,090 ft.

The series is completely conformable throughout its entire thickness. The strike is very uniformly N. 60° W. (magnetic) and the dip may be inclined a few degrees from the vertical on either side. Of the 6,090 feet of strata, 3,175 feet, or very approximately one-half of the series, are of volcanic and pyroclastic origin.

Petrography.—Under the quartz porphyries included under subdivision 1 is a light colored, strongly sheared rock which presents the appearance of a fine grained gneiss upon its cross-fracture, and that of a very fine grained biotite schist upon its foliation planes. The mica, however, is not evenly distributed, but is localized in patches. Across the schistosity minute *augen* of quartz and feldspar are visible. These features are somewhat variable, depending upon the degree of dynamic metamorphism. Favorable sections show under the microscope an abundance of quartz dihexahedra, which are often better preserved than appears consistent with the macroscopic habit of the rock. The phenocrysts are cracked, and polarize in various colors, the different tints of which, however, persist over areas relatively large. Inclusions of the groundmass do not occur. The quartzes possess sharp and linear boundaries. More frequently they are shattered and drawn out, and show strong strain shadows. In somewhat less abundance than the quartz are the feldspar phenocrysts, chiefly orthoclase in a variable state of preservation. It sometimes retains its idiomorphism, but is more commonly broken up, and the cracked fragments are embraced in large muscovite plates. Occasionally a nearly obliterated plagioclase feldspar, surrounded by white mica, can be detected. The groundmass is a fine mosaic of quartz and orthoclase, and contains much flaky biotite scattered throughout it. The constituents are all oriented with their major axes parallel, and the biotite flakelets are arranged in concentric fashion around the quartz and feldspar phenocrysts. The accessories magnetite, apatite, zircon, and titanite were found present in small proportions. A minor facies is a much darker colored schist, very fine grained and showing only small feldspar *augen*. It consists of a large number of kaolinized feldspars, shattered, and their corners abraded off, embedded in a finer feldspar mosaic, in which but a small amount of quartz is scattered. Disseminated throughout the matrix is a very large quantity of finely divided biotite, which serves to bring out the schistose structure of the rock. Its orientation around granulated areas of feldspar surrounding unshattered nuclei emphasizes the mode of reduction of the feldspars by attrition.

An important variation of the gneissic quartz porphyry is a strongly schistose facies showing abundant patches of drawn-out feldspar and a few *augen* of vitreous quartz. Upon the silvery white foliation planes of this schist are curious aggregates of sheared biotite disposed in irregular orientation. They are more or less rectangular in shape and cause the rock to simulate the appearance of the so-called "picture schists." In thin section a few shattered phenocrysts of quartz can be observed. However, one was noted which was entire and of uniform polarization tint, free from inclusions, and with but slight shadowy extinction. Its shape is such as to suggest its derivation from the dihexahedral form, but can not be conclusively demonstrated. Its boundaries are not geometric lines, but are crenulate. A peculiarity in the distribution of the interference colors suggests a well healed gash running across the phenocryst. In convergent light the section shows an eccentric uniaxial cross of a weakly birefringent mineral. The homogeneity and relatively large size of the quartz crystal, and the sharp plication of the lines of schistosity caused by it, accentuate strongly its phenocrystic character. A few kaolinized and shattered phenocrysts of orthoclase also occur. The biotite is mostly flaky and is localized in bands. The groundmass is very fine grained and consists of quartz (?) more or less interwoven with sericite. Magnetite and zircon occur as accessories. Other slides illustrate in equally remarkable fashion the anomalous behavior of the quartz. The presence of nearly undisturbed quartz phenocrysts in a highly sheared, fine grained ground is an immediately striking feature and calls for an explanation.

The sericitic quartz porphyries included under 15 and 17 differ widely from the porphyries described in the preceding paragraphs. The various facies of sericitic quartz porphyries appear to grade imperceptibly from one to the other, and often to become highly feldspathic and deficient in quartz. The commonest variety of the sericitic quartz porphyries is a strongly schistose variety presenting an irregularly mottled appearance on its foliation planes. This mottled effect is due to the alternation of areas black with biotite scales and areas of pale greenish gray color which shine with a distinctly oleaginous lustre. On its cross-fracture the rock is exceedingly dense, and only very sporadic, minute eyes of vitreous quartz can with difficulty be distinguished. Under the microscope a few badly damaged feldspar phenocrysts stand out in sharp contrast to the exceedingly fine grained ground. They are unstriated, apparently all orthoclase, kaolinized, and strongly mashed. Biotite occurs sparingly in small flakes, occasionally localized in aggregates. The groundmass is holocrystalline, but irresolvable. Some white mica can, however, be identified with certainty. A little accessory magnetite and zircon occur.

A subordinate facies of the series of quartz porphyries is a strongly foliated, very white variety which shimmers with an unctuous lustre upon its schistosity planes, due to the abundance of small mica plates. Microscopically, the rock can be characterized as a mosaic of quartz interwoven with white mica. The mica, which is distinctly pleochroic in a light greenish tint, is extremely abundant and possesses a definite linear arrangement. At certain points, however, it flows around larger areas of granulated quartz. A very little biotite is present. Some few large aggregates occur which consist entirely of scaly white mica. A little accessory magnetite and zircon are also found.

The sheared feldspar porphyry is a rather remarkable appearing rock. It is light bluish-gray in color, and is closely crowded with feldspar phenocrysts, which in consequence of the shearing that the rock has undergone, cause it to split along the foliation planes as if composed of small pebbles. In thin section the feldspars are seen to be in poor preservation: they are kaolinized, their crystallographic outlines are usually destroyed, and the corners have been abraded off; they have sometimes been cracked and the groundmass has worked in between the fragments. They have frequently been converted to sericitic aggregates, especially upon their peripheries: a band of sericite was noted closely hugging a feldspar half way round its perimeter. In another instance a sheaf-like aggregate of sericite was found separating two feldspars in near juxtaposition. The feldspars are largely orthoclase, though the plagioclase character of some few is barely recognizable on account of advanced kaolinization. An insignificant amount of biotite occurs, as does also a little chlorite. The ground is a fine mosaic of quartz and is often sericitic. A single large fragment of quartz, showing strain shadows, differentiated itself from the ground, and appeared to represent the remnants of a phenocryst, but the evidence was not decisive. Apatite in needles, and magnetite in quite large aggregates, were relatively abundant. A little epidote and a piece of tourmaline were also found.

The rock called a tuff under formation 11 is of grayish-green color and is dotted with rather numerous, small turbid white phenocrysts in a very fine grained groundmass. The foliation is rude, though very distinct. Under the microscope the porphyritic feldspars are found largely untwinned, though a few show very narrow striations and small extinction angles against the lamellae. The original character of the feldspars is indicated by the circumfluent schistosity; by their occasional strong idiomorphism and by the frequent peripheral granulation zones; and by their homogeneity and freedom from inclusions of the minerals of the groundmass. In certain instances the sharp abutment of the feldspars against the cryptocrystalline ground, and the absence of granulation products seem to show in the case of rounded corners evidences of magmatic corrosion.

The matrix consists of biotite flakes and some chlorite, disseminated throughout a limpid, feebly polarizing paste. Magnetite occurs as accessory, and occasionally apatite needles are included in the feldspars and more frequently lie scattered in the groundmass, where they show marked evidences of cataclastic phenomena.

It is apparent that the microscopic diagnosis is not conclusive as to the massive or pyroclastic origin of this rock. The field relations, however, show that a continuous gradation exists between this type of rock and others whose clastic origin is more readily evident. It occurs as interdigitating masses with the tuffaceous conglomerate, occasionally even forming the matrix in which the pebbles lie embedded, and its gradual transition can be traced on the one hand into the normal clay slates and into the tuffaceous slates on the other.

The tuffaceous conglomerate presents an exceptional development on the section across Timber Gap. Interdovetailing with feldspar tuff are heavy lenses of coarse conglomerate consisting of well rounded pebbles of quartz, red chert, shale and conglomerate up to the size of a man's head. These occurrences are local and thin out rapidly along the strike. The more tuffaceous portions show occasional drawn-out pebbles (three-quarters of an inch long) included in a strongly sheared schist of fine grain. The color is slaty, tinged with green, and the foliation planes show but a dull lustre, except where biotite has locally been developed, or where infrequent patches of sericite occur. Some little eyes of glassy quartz can with careful search be discovered.

Under the microscope, the immediately noticeable feature is the exceedingly large quantity of flaky biotite, with chlorite, which is disseminated throughout the cryptocrystalline ground. Some small lathes of white mica are apparent. Sporadic phenocrysts of feldspar occur, badly altered, and frequently converted to sericitic aggregates. The foliation is around their abraded corners. Between crossed nicols a long slender feldspar rectangle was noted somewhat inclined to the foliation. Towards one end it is bent and fractured, and definitely deflects the stream of schistosity. It is twinned according to the Carlsbad law, and the two halves give simultaneous extinction when the trace of the twinning plane is parallel to the cross-hairs, and is therefore orthoclase. A few irregular fragments of quartz, showing strain shadows, were found, and proofs of their pyroclastic origin still remained undestroyed. These were found in the survival of pyramid faces, and the occasional presence of straight edge boundaries indicative of their original idiomorphic character. Some tourmaline is present, and was found in three distinct forms: as a small stout prism; as sector of a spherulite; and as a spongiform aggregate. This is conclusive proof of the non-allothogenic origin of the tourmaline.

The clay slates in general possess the plane-parallel cleavage, but, nevertheless, frequently grade into finely foliated schists. Transitions between clay slates, phyllites, and microcrystalline biotite schists are of constant occurrence. In the strongly schistose varieties the biotite becomes macroscopically visible in the form of minute scales. The microscope shows that the clay slates contain a large amount of flaky chlorite, which becomes replaced by biotite with advancing schistosity. Intercalated with the clay slates and phyllites are beds of slates showing curious elliptical depressions and pustular swellings about a tenth of an inch in diameter upon the cleavage surfaces. This peculiar phenomenon was developed in extraordinary degrees in beds occurring between a succession of normal clay slates exposed in a creek-cutting northeast of Mineral King. The exposure was at the maximum distance possible from the granite. A thin section cut from this rock when held to the light shows a remarkable satiny shimmer, and reveals a large number of variously oriented eye-like areas surrounded by carbonaceous bands. Under the lens the rock is found to be exceedingly fine grained and dimly polarizing. Some quartz, and an abundance of green chlorite is recognizable with certainty. The chlorite is very feebly birefringent and shows a faintly luminous ultra-blue. Large areas are completely isotropic owing to the overlapping of chlorite scales. Some *thonschiefernadeln* and a few minute prisms of tourmaline were noted. Carbonaceous matter is quite abundant. The elliptical areas previously mentioned are sometimes bounded by bands of chlorite, but are more usually defined by carbonaceous material. They do not differ essentially in composition from the ground, but in a few cases were found to contain a more brightly polarizing mineral. It gave straight extinction, and appeared to be white mica, but its identity could not be conclusively established.

An interesting quartzite occurs near the Empire mine (altitude 10,000 feet and N.E. of Mineral King). It is massive and non-schistose, and shows three splendid jointages which cause it to break in small polygonal blocks. Particles of a yellowish green mineral are uniformly scattered through it, and lend it a somewhat granitic habit. Under the microscope, the clastic origin of the rock is readily apparent. Numerous quartz grains show their detrital origin in the subangular character of their outlines. They have received a common orientation and show strain shadows, and some have been crushed. Rounded grains of altered plagioclase are quite abundant. A portion of the feldspar is unstriated, and may be monoclinic. A not inconsiderable amount of decomposed reedy hornblende is distributed throughout the slide. With it is a little biotite and chloritic material. A fine grained, feebly polarizing paste, whose exact nature is indeterminate, constitutes a sort of cement for the clastic particles. Some accessory magnetite, pyrite, titanite, and abraded zircon occur scattered through it. This rock seems, therefore, to represent an indurated arkose sandstone.

Sheared Quartz Porphyries from the Little Kern.—Associated in conformable sequence with the sedimentary series on the Little Kern in both strike and dip, are several hundred feet of sheared quartz porphyries and tuffs. They are of pearl gray color, of waxy, unctuous lustre upon their foliation planes, and show numerous easily recognized dihexahedra of quartz, which lie embedded in an aphanitic base. They are macroscopically identical with the quartz porphyries described by Turner from the Downieville Quadrangle, and placed by him as very probably of Jura-Trias age. One facies here, however, shows also porphyritic glassy feldspars.

Under the microscope the numerous quartz phenocrysts show severe strain shadows. Some have been scattered and granulated. The outlines of the quartzes are usually irregular, but occasionally bipyramidal forms occur showing corrosion and embayment. A slight conchoidal fracturing of the crystal edges is sometimes apparent. Feldspars are not numerous, and are poorly preserved, usually drawn out and kaolinized. The groundmass is extremely fine grained, presenting in ordinary light a sort of shagreened appearance due to the interweaving of micaceous material. The development of this material often serves to bring out the former flow structure. Magnetite and some disjointed apatite needles were noted as accessories. Small irregular groups of minute tourmaline prisms are of comparatively frequent occurrence in the groundmass.

A section cut from a hand specimen taken from near the intrusive granite showed somewhat surprising features. The quartz porphyry at the contact is standing on edge and does not differ macroscopically from the previously described facies, which was taken from altitude 8,300, Little Kern trail. The microscope shows that the porphyritic quartzes have retained their integrity and idiomorphic habit in nearly perfect preservation. They display strong undulose extinction, and may occasionally be fractured to small extent, but rarely show traces of granulation. The ferromagnesian minerals are conspicuously absent from the quartz porphyries.

The tuff associated with these acid volcanics does not differ greatly from them in its physical aspect. It is, however, more massive, and does not contain numerous porphyritic quartzes. Included in it are dark lenticular patches, representing fragments of extraneous origin. Under the microscope only a few irregular fragments of quartz are apparent, and these are affected by strain shadows. Phenocrysts of orthoclase are more numerous, and frequently retain their idiomorphic habit. Some are fractured, and the fragments, especially the corners broken off from the phenocrysts, show cross-hatched twinning. A few of the larger feldspars display the microcline structure in splendid perfection. The delicate cross-hatching is on a fine scale, and has been developed uniformly over the area of the feldspars. The plagioclases are less abundant than the potash feldspar and have been somewhat capriciously affected by the dynamic metamorphism. Some still show the re-entrant twinning angles; others are peripherally granulated; and a lath was found broken into three pieces and the fragments separated.

Phenocrysts are not abundant, and the ferromagnesian minerals are nearly absent. A few small strips of biotite were found, as were some irregular patches which appear to represent localizations of flaky biotite. The ground is cryptocrystalline, and contains scattered through it very minute scales of biotite. Some magnetite, a few zircons showing perfect terminations, and some small prisms of tourmaline occur as accessories.

A continuation of the same tuff is found exposed near the lakelet south of Vandever Mt. It is a gray-blue rock liberally sprinkled with glassy quartzes, and contains abundant inclusions of sharp angular slate fragments up to three-quarters of an inch in length. The rock weathers to an ash-white, and the small dark fragments lend it a strong porphyritic aspect. The schistosity is but feebly developed. Under the microscope the numerous glassy quartzes are immediately noteworthy. They are angular and jagged, often assuming fantastic forms. Powerful strain shadows are apparent, and the longer axes of the crystals have received a common orientation. Occasionally the jagged points are shattered, and sometimes the quartzes are surrounded by a very faint granulation aureole, but usually the demarcation between phenocryst and ground is absolutely precise. Some small sericitic aggregates were found, as were a few inclusions of carbonaceous shale. The groundmass is extremely fine grained, and contains a great deal of flaked chloritic matter disseminated through it.

On Monarch Creek at 8,500 feet is a strongly sheared sericitic quartz porphyry less than 100 feet thick. It is of light pearl gray color and shows an oily lustre upon its foliation planes. The porphyritic quartzes are quite abundant, and their frequent idiomorphic character is often apparent to the unaided eye. Under the microscope the outlines of the quartzes are seen to be usually of geometric perfection. The dihexahedral form is often modified by corrosion and embayment phenomena, and sometimes by a slight conchoidal fracturing. Severe strain shadows are frequent, and occasionally the phenocrysts have been cracked, allowing the matrix to work in between the separated portions. The feldspars, of which a little is triclinic, are very sparingly represented, and are poorly preserved. A little biotite is present in flaky aggregations. The groundmass is a fine grained aggregate of quartz and sericite. In it occur some disjointed and faulted apatite needles; cataclastic zircons showing both splintery and idiomorphic terminations; and some crisscross aggregates of minute tourmaline prisms.

The More Basic Volcanics.—In the creek descending from the 9,883-foot Peak west of Timber Gap is a 50-foot thickness of highly sheared volcanic rock intercalated between beds of clay slates. The rock differs from the others of the region in containing abundant triclinic feldspar and a weakly pleochroic light green hornblende. Cataclastic phenomena are illustrated in great abundance. The granulated remains of phenocrystic quartz seem to be present, but are not conclusively demonstrable. The chief interest attaching to this rock is due to the peculiar occurrence of tourmaline in it. The tourmaline was found occurring as a peripheral fringe around a shattered feldspar, and could be seen sending apophysal tongues into the core of the phenocryst.

The creek heading near the Empire Mine (N.E. of Mineral King) crosses several hundred feet of altered volcanic rock. The rock is of bluish gray color, fine grained, and shows but a rude schistosity. Its most conspicuous feature is the abundance of sheared streamers of ferromagnesian material, commonly replaced by epidote. Under the microscope some drawn-out aggregates of intensely pleochroic basaltic hornblende can be seen to have escaped the general alteration. Some large masses of granular epidote surrounded by opaque earthy material occur in considerable areal proportions. Cataclastic feldspars, too far affected by decay to leave their exact nature determinable, are present in no great abundance. The groundmass is cryptocrystalline. Broken apatite needles, and magnetite with associated leucoxene, constitute the accessories.

Large bodies of sheared andesite (Pl. 29B) occur on Crystal Creek at an altitude of 10,000 feet. Its color is a dark grayish green, interspersed with numerous regular patches of flaky biotite. These aggregates assume rectangular forms, uniformly oriented, and suggest a derivative origin from former phenocrysts. In this section a very abundant generation of large feldspar phenocrysts, affected by dynamic agencies and nearly obliterated by kaolinization, becomes apparent between crossed nicols. Some of the feldspar crystals still show evidence of their triclinic character, and upon a favorable section a symmetric extinction angle of 22° was obtained. Dark aggregates of flaky biotite are common, but nothing can be discerned as to their origin. The matrix is cryptocrystalline, and contains a great deal of chloritic matter flecked through it. Some accessory magnetite with pyrite cores, and some secondary epidote are also found.

THE CONTACT.

It has been pointed out that the sedimentary rocks form an elongated belt surrounded by granites. The vigorous erosive activity has laid bare the contact at numerous points and has revealed clearly the intrusive nature of the plutonic rocks.

Porphyritic modifications, and in one instance, a rude gneissic structure, are occasionally developed as marginal facies. The porphyritic modification is best displayed at the upper Monarch Lake. The granite, here a coarse quartzose microcline granite of normal hypidiomorphic habit, is converted at the contact into a closely crowded assemblage of microcline phenocrysts embedded in a fine grained mesostasis consisting of quartz and small flakes of biotite. A similar modification is found on the western side of the belt in the White Chief cirque.

The irruptive is accompanied by extensively ramifying systems of apophyses, which are, however, never very long. The longest found was 20 feet thick and followed the strike of the schists nearly a thousand feet. The larger veins, as a general rule, cut across the schistosity at random, but the anastomosing system of capillaries to which they give rise, tend to seek out the planes of weakness. Their fineness, and acutely serpentine character, argue a great degree of fluidity for the intrusive magma.

In addition to the thermal metamorphic influence of the granite, it has at points been active dynamically also. West of the Timber Gap, the irruptive has locally bent the schists from N. 45° W. around to N. 25° E. and back again to the normal strike. Extensive shattering of the strata, especially in the Silver Lakes region, has taken place, but the results are complicated by the internal movements which the belt has undergone.

The granite at the contact frequently contains included large numbers of angular fragments of schists. Occasionally they show some rounding of the edges, and even embayment, or may be surrounded by a resistant aureole which causes them to weather in relief. Aplite dykes and pegmatites are common at the contacts and vicinity, and were noted to fault from two or three inches the basic segregations previously described.

CONTACT METAMORPHISM.

The conditions are distinctly unfavorable for the systematic study of contact metamorphism. This is principally due to the fact that in the great majority of cases the strike of the strata is nearly parallel to the contact. Both ends of the belt are unfortunately obscured, either by morainal debris or by decomposition products. Other deterrent factors are the shattered condition of the strata near the granites, and the frequently inaccessible position of the contact on precipitous cirque walls.

This last cause was especially felt in the case of a metamorphic clay slate in the Crystal Lake cirque. The contact could not be approached closer than about 400 feet. At this distance the rock is dense and fine grained, massive, and of dark slate blue color. Scattered through it in sparse porphyritic fashion are small prisms of tourmaline, 1 mm. in diameter and several mm. in length. Under the microscope the tourmaline shows a nearly circular cross-section of yellowish brown color. The section is fairly homogeneous and free from inclusions of the groundmass, but is surrounded by a heavy peripheral fringe of carbonaceous material. The tourmaline contains some liquid inclusions which are disposed in radial fashion. The matrix is composed of rectangular and quadratic andalusite sections embedded in a small amount of interstitial quartz, and a large quantity of black opaque material, forming nearly half the bulk of the slide. Ignition caused the rock to bleach, proving that the included material is of organic origin. The andalusite is filled with carbonaceous matter, which, however, shows little or no tendency to systematic orientation. In one or two instances only was a crude chiastolite cross noted. Pleochroism is absent, and differences of absorption are feeble. Some small patches of brownish biotite are also found.

The limestones have in all cases become marmorized near the contacts. In the White Chief cirque north of Vandever Mt. are large beds of coarsely crystalline white limestone paralleling the contact, which is marked by a four-foot zone of garnet rock. The limestone contains bodies of magnetite ore, and large metasomatic deposits of zinc blende. Pieces of the sulphide ore are frequently studded with small honey-yellow garnets (grossularite). Under the microscope the garnet rock is seen to be composed for the most part of common garnet, entirely isotropic. Some monoclinic pyroxene of reddish brown color and of refractive index very near that of the associated garnet is present in small amount. Its extinction angle exceeds 40°, and it therefore falls toward the hedenbergite end of the diopside series. A little wollastonite is also found. Calcite forms an irregular mesostasis serving to bind together the other constituents.

A local phase of the metamorphism of the limestone is a fine grained variety specked with small particles of a dark greenish mineral. The microscope shows that the dominant constituent is a dusty looking carbonate. Associated with it in smaller proportions is a clear limpid mineral displaying the characteristic calcite twinning. A qualitative test of the rock gave a large precipitate of magnesium, indicating that the brownish carbonate is probably dolomite. Subsidiary amounts of diopside, which have frequently been converted to colorless serpentine aggregates, are also found. Areas of fibrous chalcedony are quite common. Some little reddish brown garnet and a few granules of magnetite, which were not associated with the serpentine, constitute the accessories.

Along the creek descending from the 9,883-foot Peak the following section is exposed *across* the strike, N. 45° W.:—

Porphyritic hornblende—biotite granite.		
Sheared quartz porphyry	300	feet
Siliceous schist	3	”
Clay slates	50	”
Banded quartzite	150	”
(containing a granite dyke 8 feet wide.)		
Knotted schist	25	”
Crystalline limestone, banded blue and white	75	”
Blue crystalline limestone	50	”
Laminated quartzite	40	”
Hornfels	10	”
Schistose quartzite	50	”

The knotted schist is a slate-colored rock, distinctly schistose, and owes its knotted character to the accumulation of biotite flakes on its cleavage surfaces. Perpendicular to the foliation planes the knots form flat lentils less than 1 mm. thick, and varying up to 1 cm. long. Under the microscope the very finely granular character of the rock becomes apparent. A large amount of minute biotite scales, of chocolate brown color, is uniformly distributed throughout the slide. Equally noteworthy are numberless small stout tourmaline prisms of sharp idiomorphic habit. In some crushed quartz aggregates white mica has been developed. The bulk of the rock is quartz, but all evidences of clastic origin have been obliterated. Some darker colored areas of irregular elliptical shape are found, and seem to owe their peculiar constitution to aggregations of overlapping scales of micaceous material.

The hornfels is an extremely tough and compact rock of dense grain and dark slate blue color. The characteristic feature under the lens is the rather abundant development of andalusite, usually in rude radial aggregates. Crystallographic outlines are rare, but the sections tend to assume a longitudinal habit. They are colored brownish due to included carbonaceous material; pleochroism is not appreciable. The absorption is fairly strong and is a maximum in the direction of the length. The main mass of the slide is finely granular quartz, containing a large amount of pyrite and carbonaceous matter. This abundance of included material masks the presence of the andalusite in ordinary light, but between crossed nicols its brighter interference colors (yellows and blues of the 1st order) cause it to stand out in conspicuous contrast.

Some limited cases of thermal metamorphism of the volcanic rocks were found, chiefly to the west of Timber Gap. At the contact of the granite and the quartz porphyries a narrow zone of hornfels, two to three inches wide, has been formed. It is perfectly massive, extremely tough, and has a sort of vitreous lustre. Under the microscope quartz is found to be the dominant constituent. It is characterized by containing numerous circular, and even rectangular liquid inclusions. Orthoclase is quite abundant, and with it is a considerable amount of microcline. Some little micrographic intergrowth is also recognizable. Biotite and muscovite are present in subordinate proportions. A catalastic zircon was noted included in a muscovite plate. Magnetite and zircon constitute the accessories. The structure is allotriomorphic granular.

A less unequivocal case of contact metamorphism was found west of the ridge. Here the quartz porphyry, in which the original dihexahedral character of the quartzes is better preserved than ordinarily, contains a small amount of common garnet. The garnet is completely isotropic; it possesses a "sieve structure" and contains inclusions of quartz. This specimen was taken 100 feet from the contact. The various other sheared porphyries failed to show any traces of garnet.

THE RELATION OF THE MINERAL KING BELT TO THE GRANITE.

The relatively greater uplift of the southern portion of the Sierra Nevada has long been recognized, and LeConte has pointed out that the intensification of the erosive activities produced thereby, has effected an almost complete denudation of the irruptive granites. In the High Sierras a few small detached areas and narrow belts of schistified rocks are all that remain of the extensive roof under which the plutonic magmas cooled. Such isolated remnantal patches are known to occur at Mount Tallac, Mount Dana, Mammoth, and Mineral King.

At Mount Dana and neighboring parts of the mountain crest the stratified rocks can be seen resting in irruptive discordance upon the more or less uneven surface of the granite and in part sunk into it.* At Mineral King, however, the relations are rather different. Examination shows that the schists instead of reposing upon a batholitic surface, are embedded beneath the general surface of the granite. They occupy a trough-like depression the bottom of which is not revealed, in spite of the fact that the hypsometric range within this limited area is more than 6,000 feet. This resemblance to a trough-like character is accentuated by the deep strike valleys which selective erosion has carved out in the clay slates, and it is doubtless due to this depression beneath the zone of most vigrous erosion that the rocks of this belt owe their preservation. The sides of the trough are occasionally visible, especially upon the cirque walls on the eastern side, and at Silver Lake the contact is revealed to a depth of over 500 feet. The exposure shows that the granite abuts upon the sedimentary rocks in a locally uneven and irregular surface, but one which, in general, approximates verticality, or even inclines slightly to the east. At other points it could be seen dipping to the west. Detailed mapping on the contour sheet shows that the contact planes depart indifferently from the vertical. The fact that the belt becomes narrow on low ground indicates, however, that the planes tend to converge, rather than diverge, with increasing depth. The map shows the close relation between the dimensions of the belt and its internal structure. The great narrowness across the strike and the relatively great length are immediately apparent. The correspondence between strike and prolongation is complete south of Farewell Gap, but to the north a divergence sets in, amounting to as much as 20°. In spite of the close accordance between the length of the belt and the strike of the strata, it will be noted that the course of the contact is often directly across the edges of the schists. Along the entire periphery evidences of the intrusive nature of the granites are abundant, and the various criteria for the discrimination of irruptive contacts are everywhere visible in the form of intrusion breccias, apophyses, marmorization of the limestones, and the formation of hornfels zones. Numerous fragments of schists included in the granites show that the schistification of the series preceded the ascension of the plutonic magmas, and this evidence is in confirmation of the relations found to hold true throughout the Sierra Nevada that the schistosity of the invaded formations is independent of the contact planes, and was not produced by the intrusive igneous rocks.*

---

* Prof. A. C. Lawson, oral communication.

The post-granitic invasion of the sedimentary series on Monarch Creek by the tonalitic magma has produced a deep embayment in the contact line and has isolated a heavy body of garnet rock which caps the summit of the 11,530-foot ridge. A small patch of schists at the lake at the head of Cliff Creek seems to owe its position to the same cause, and is now satellitic to the main mass. With these exceptions the Mineral King belt constitutes an isolated, integral unit, surrounded by granites of synchronous origin.

---

* Turner, however, cites an exception from the Bidwell Bar Quadrangle.

The periphery of the belt is lined with granite peaks which commonly exceed 12,000 feet in altitude—Sawtooth, 12,340 feet, Florence, 12,405 feet, and other peaks unnamed as yet. West of Vandever the granite plateau maintains a height of 11,200 feet with individual peaks rising to 11,800 feet. North of Cliff Creek the vast assemblage of granite peaks "like the billows of a choppy sea," fall into a general level at 12,000 feet. The lowest exposure of the sedimentary rocks on Cliff Creek was found at 7,000 feet, or a difference of 5,000 feet. Even in the heart of the belt, that is, at the site of Mineral King, the difference in altitude between the highest and lowest exposure of the sedimentary series is more than 4,000 feet. If we assume that Sawtooth, which is on the immediate periphery, approximates toward the former surface of the batholith, the difference will amount to more than 5,000 feet. The contact passes through the region of maximum glacial degradation where the mountain crests have often been reduced not less than one thousand feet.* It is, therefore, evident that 5,000 feet represents a minimum estimate of the amount of depression of the sedimentary series beneath the general level of the granite surface.

A belt of stratified rocks thus surrounded and enveloped by plutonic magmas was situated in extremely favorable environment for the operation of thermal metamorphic agencies. Yet the alteration effected has been small, and always local. The large body of clay slates, which examination shows to be the most susceptible to metamorphism, are practically unaltered. This is all the more surprising when considered in the light of the facts from other portions of the Sierra Nevada. Turner reports upper Jurassic (Mariposa) clays slates metamorphosed to chiastolite schists, over a distance of 6,500 feet along the strike. At Cisco on the Colfax Quadrangle Lindgren has mapped in several square miles of hornfels rocks, and has shown the existence of a broad contact zone half a mile wide and several miles long. The conditions there parallel closely those obtaining at Mineral King. The plane of intrusive contact is nearly vertical, and is in its general trend closely coincident with the strike of the invaded formations.

---

* A. C. Lawson, Bull. Dept. Geol. Univ. Cal., Vol. 3, p. 361.

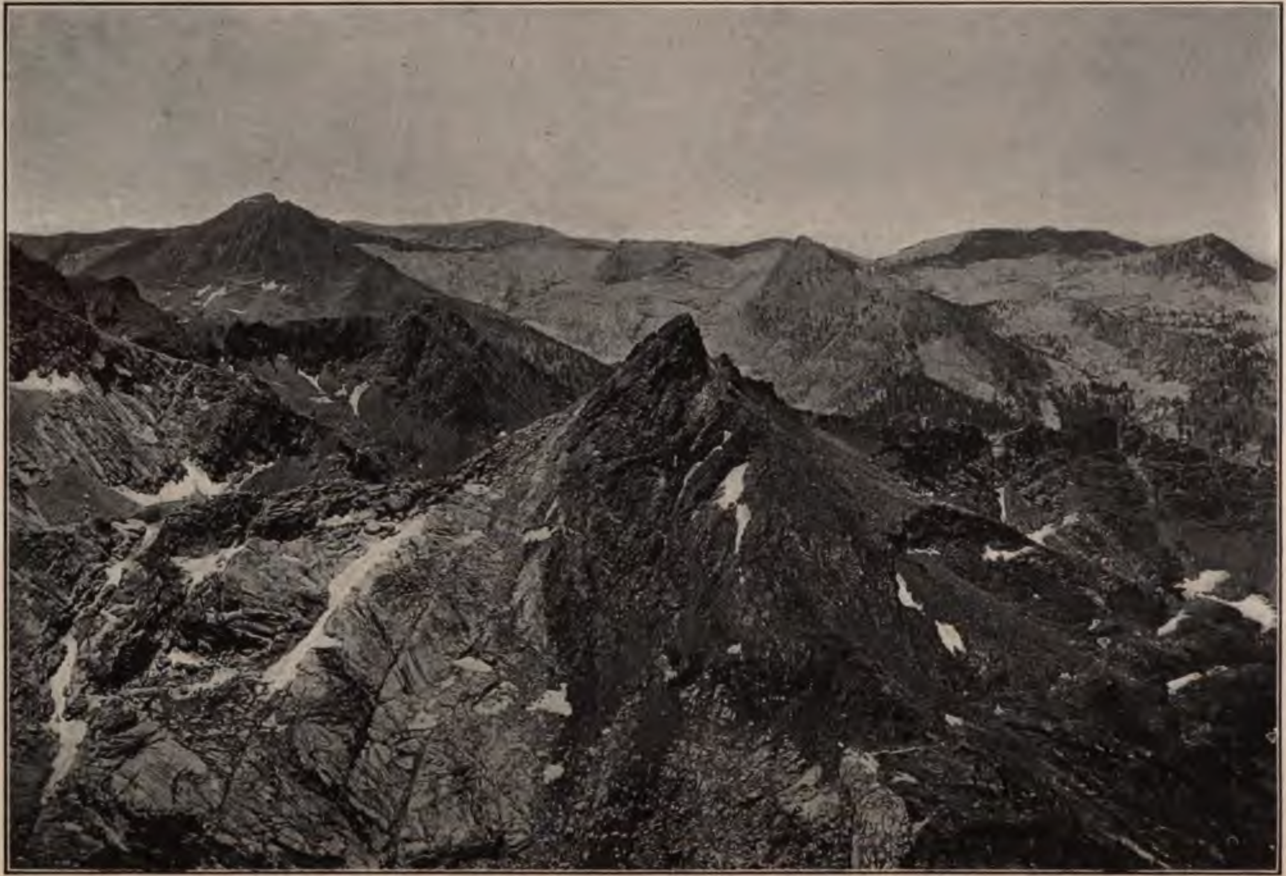
The belt of rocks with which we are concerned narrows down south of Farewell Gap to as small a thickness as 4,200 feet across the strike. The major portion of the series consists of normal clay slates, and comprises the axis along which the valley of the Little Kern has been eroded. Two conditions were unfavorable to the metamorphic activity of the granite; firstly, the verticality of the contact walls, and secondly, the parallelism of the strike of the strata with the contact plane. Opposed to these unfavorable conditions were the great narrowness of the belt, and the simultaneous supply of heat from two opposite sides. The degree of metamorphism, therefore, appears relatively small, and is but insignificant when compared with what has been effected in other portions of the Sierra Nevada under less favorable conditions. The frequent occurrence of tourmaline in the invaded formations, both sedimentary and volcanic, seems to show that pneumatolytic processes, at least, have been comparatively active.

The description of the intrusive nature of the contact shows that the trough in which the sedimentary rocks lie embedded cannot have originated through faulting, either of simple or graben character. The irruptive character of the granites has been sufficiently emphasized and the detailed evidence presented as to the sunken condition of the stratified belt of rocks. It is, therefore, evident that the Mineral King lens represented a portion of the batholithic roof which has foundered during the intrusive ascent of the igneous magma. The granites were still in a highly mobile condition when this event took place, but evidence deduced from the incommensurate degree of thermal metamorphism seems to indicate that the submergence did not long antecede the final consolidation of the magma.

Various severe internal movements have affected the stratified rocks. At Timber Gap compressive forces acting along the strike have caused severe buckling of the limestone beds. On Crystal Creek the same forces acting as an oblique shear have shoved the beds over one another, and have produced an appearance resembling an erosional unconformity (Plate 29A). The angular discordance amounts to 14°. The apex of the acute angle is occupied by brecciated masses of quartzite, and crushed horses of quartzite are common in the limestones. On the opposite side of the ridge shown in the photograph the strata have been intensely shattered and contorted. Owing to the near proximity of the contact it is impossible to discriminate the thermal rending from the crumpling due to a sort of buttress action.

The granites of the region show no macroscopic evidences of deformation. The microscopic investigation, however, showed frequent straining of the quartz, and occasional faulting of apatite needles. These minor cataclastic phenomena constitute the last page in the diastrophic record of the Mineral King area.

University of California,
May, 1905.



View looking south-west from Sawtooth. Granite plateau behind Vandever Mt. in background; granite contact in foreground, showing embedded character of the Mineral King belt of sedimentary rocks.

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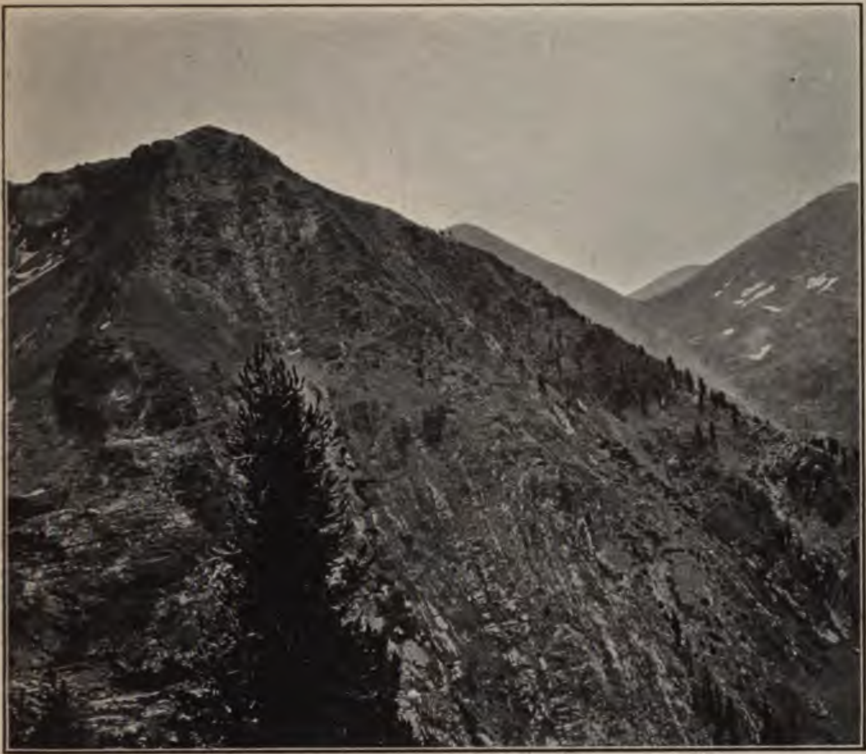
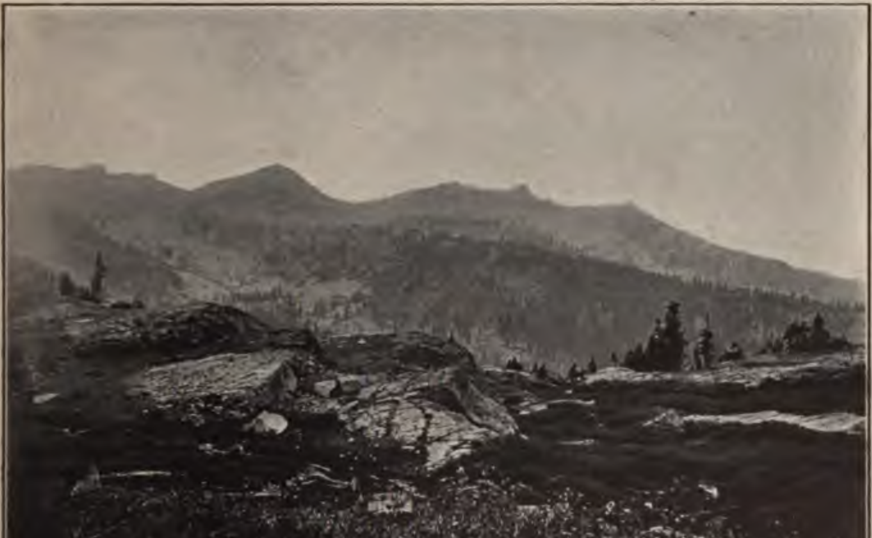


A.—Angular discordance produced by oblique shear on Crystal Creek



B.—Glacial benches quarried out of sheared andesite on Crystal Creek. Height, 15 feet. Showing utilization of jointages, and ineffectiveness of abrasion.

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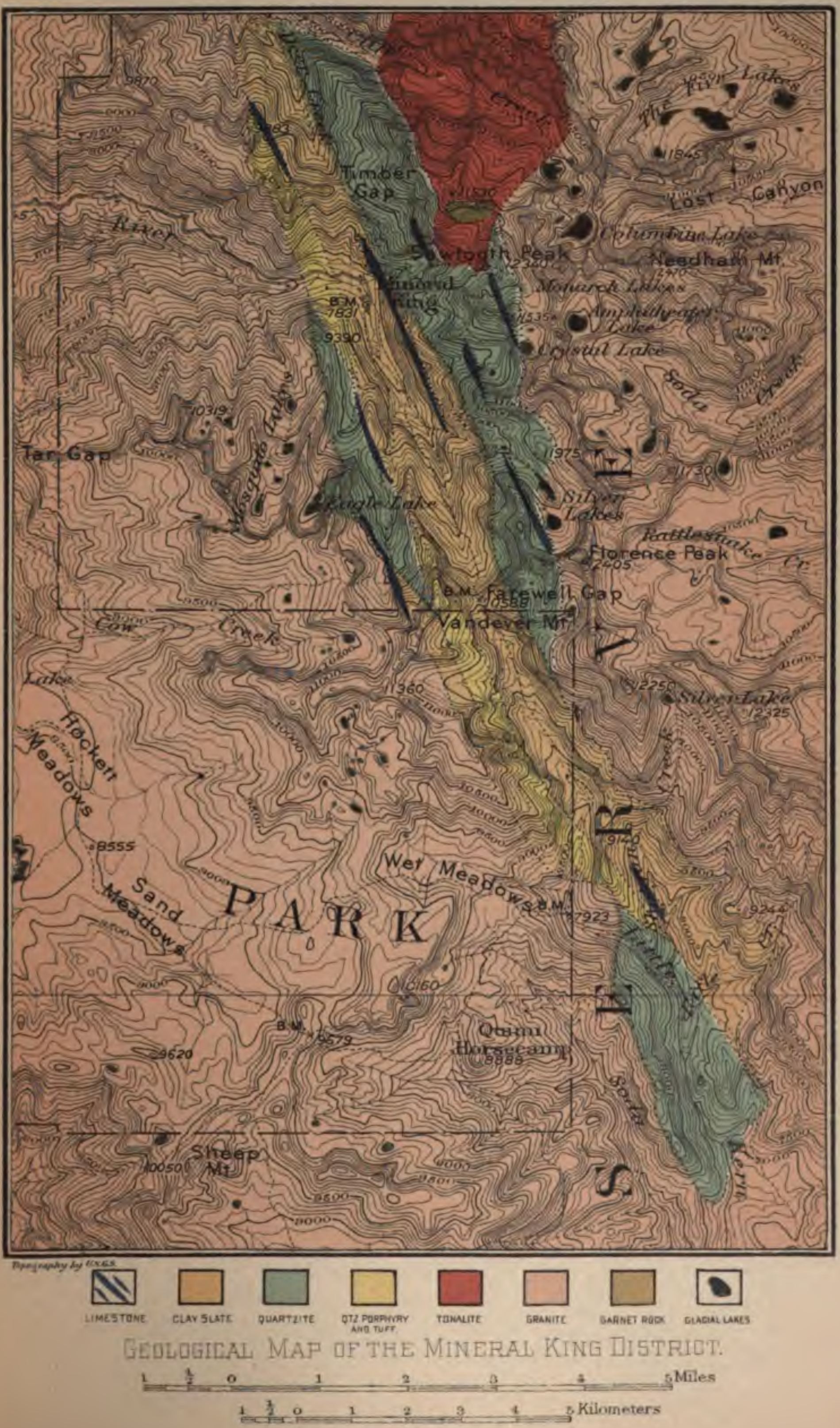

GEOLOGICAL MAP OF THE MINERAL KING DISTRICT.

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 100 feet.

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UNIVERSITY OF CALIFORNIA PUBLICATIONS
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COLD WATER BELT ALONG THE WEST COAST OF THE UNITED STATES

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BY

RULIFF S. HOLWAY

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INTRODUCTION.

Although considerable attention has been paid to the question of ocean currents off the west coast of the United States, yet much work remains to be done, that accurate information as to the limits, direction and temperature during the year of the various streams or drifts may be ascertained. The Pilot Charts of the North Pacific, issued monthly by the United States Hydrographic Office, give for each of the four seasons a somewhat schematic current chart which is virtually a composite of the observations received by that office. Upon the face of each sheet there is a statement printed in red, calling attention to the meager data upon which the currents are charted. In the preparation of the Pilot Charts, only actual reports by officers crusing in the Pacific are considered and particular attention in observing and reporting currents is requested of all mariners.

The amount of current reported by a vessel is the difference in the position of the vessel each day as obtained by dead reckoning and the position obtained by astronomical observation. In getting the position by dead reckoning, there are several sources of error. Among these are the variation of the log in finding the velocity of the ship, the failure of the man at the wheel to hold the ship accurately to the prescribed course, and the uncertainty as to the exact variation of the magnetic needle. This last source of error may be of considerable amount. The North Pacific Pilot Chart for February 1904 says: "Taking the whole of the navigable world into consideration, it would be conservative to state that the general uncertainty in the heading of a ship at sea, arising from an inaccurate knowledge of the variation of the needle, is as much as two degrees." This alone would make a discrepancy of 15 to 20 miles between the calculated and the true position of a fast steamer at the end of each day's run. Turning to the other half of the problem, it is found that a probable error of 2½ miles must be allowed in obtaining the true position by astronomical observation.* The difference between the ship's position as determined by these two methods with the possible sources of error is reported as current or drift. It is well to note that the reports of steamers have not the same value as those of sailing vessels. The sailing vessel is occasionally becalmed for an entire day and then the difference in position between two astronomical observations gives a reasonably accurate determination of the drift. The normal rate of a ship being known, it would seem as if it might fully be allowed for, and hence the current might be determined from a vessel under way, with an equal accuracy as from a drifting ship. This would be true were it not for the fact that ocean currents and drifts are not large masses of uniformly moving water, but rather relatively narrow streams with bands of calm water or even counter eddies between. A steamer moving rapidly may pass through several narrow streams of differing velocity or even differing direction and its report of current would then be the algebraic sum of the various currents encountered. A becalmed ship or even a slow-moving sailing-ship is apt to remain in one stream for the entire 24 hours. This is supposed to account for some of the widely differing reports of sailing vessels and of steamers in traversing the same region. With the increasing commerce of the Pacific the number of reports from both steamers and sailing vessels will increase, and reasonably correct information will be obtained for the zones traversed by regular vessels. For the parts of the ocean out of the usual courses laid down, reliance must be placed in the scientific expeditions devoted to oceanic research.

---

* Estimate by Professor George Davidson.

An important addition to the reports of currents encountered by vessels are the so-called "bottle tracks." Bottles usually made of rubber are thrown overboard with an inclosed slip giving the latitude and longitude of the ship at the time. On the bottles is a printed request that they at once be returned to the authority conducting the investigation, with a statement of the time and place of finding. The bottle track is the line connecting the place of starting and the place where found. A minimum rate of drift is thus established. The line of drift and the time that the bottle may be stranded on some coast before being found are the elements of uncertainty. If the bottle is so weighted as to expose practically no surface to the wind, its movement depends entirely on current or drift and "bottle tracks" thus form a valuable element in current determination.

A third important source of information is found in the constantly growing mass of data on ocean temperatures. The thermometer is one of the most reliable instruments in determining currents. Unfortunately much of the data for ocean temperatures on this coast is scattered through the reports on file in the Hydrographic Office and is not accessible to the public. It is to be hoped that more of this will be tabulated and made available to investigators as has been done by Mr. C.

H. Townsend* for the work of the Albatross for the years 1883–1900. The original observations upon which this paper is based are found largely in Mr. Townsend's compilation and in the valuable work of Admiral Makaroff† which tabulates temperatures taken in the North Pacific from 1804 to 1890, but does not include the work of the Albatross.

TEMPERATURE OBSERVATIONS OF THE TUSCARORA.‡

Some of the most marked peculiarities in the temperature distribution off the west coast of the United States are well shown by tabulating the observations of Commander Belknap of the U. S. S. Tuscarora. In 1873 the Tuscarora had been detailed for the purpose of finding a suitable route for a cable between the United States and Japan. A series of soundings was made on lines running west from the Pacific Coast to determine the slope and the general nature of the ocean bottom near shore. Incidentally the temperature of the ocean water was taken—the series of observations is fairly complete for surface and bottom temperatures but rather incomplete for serial temperatures showing the conditions at intermediate depths. The surface temperatures obtained on 14 lines running approximately west from the coast and at intervals from Cape Flattery to San Diego are given in the table herewith. The first temperature in each line is the temperature found nearest shore. Unfortunately this is not at a constant distance from the coast line. Where the difference is material, the first sounding is set over a corresponding amount in the table.

The first line of soundings was made September 17 to 20, 1873; the eight lines from Flattery Rocks to San Francisco, October 20 to November 6; the lines between San Francisco and San Diego from December 20 to 30. As these observations were distributed over a period of three months, each line of soundings must be taken by itself to avoid confusing seasonal

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* U. S. Fish Commission, Report for 1900, pp. 387-562.

† Makaroff, S. Le Vitiaz et L'Ocean Pacifique, St. Petersburg, 1894.

‡ Belknap, Geo. E., Deep Sea Soundings in the North Pacific. U. S. Hydrographic Office, 1874.

Found also in Makaroff's work.

SURFACE TEMPERATURES BY COMMANDER BELKNAP, U. S. S. TUSCARORA
OFF AND ON SHORE SOUNDINGS FROM CAPE FLATTERY TO SAN DIEGO, 1873

Shore end of line	First Sounding Latitude	First Sounding Longitude	Date	Temperatures Inshore																	Offshore	Northing or Southing
	N	W	1873																			
Cape Flattery	48° 35′	125° 25′	Sept.	50.4	51.8	53.2	56.5		54.6					59.0					58.0			1° 11′ N
Flattery Rocks	47 14	126 42	Oct.								57.0	57.1		57.2				58.5				1 00 S
C. Foulweather	44 52	124 47	”	50.4	51.2	52.3	53.3				57.0				59.0					59.5		0 26 N
Empire City	43 07	125 14	”	53.2					52.1	54.9					57.6							0 17 N
Trinidad Head	41 00	124 27	”	48.5	49.4	50.2		52.0			51.0			54.6			58.1				54.8	0 54 N
C. Mendocino	40 18	124 30	”	49.6	55.6	51.6		53.2		55.0												0 09 S
Pt. Arena	39 04	124 40	Nov.	52.8		53.1	55.8															0 02 N
Salt Point	38 31	123 46	”	51.7	52.8					57.9		58.0										0 06 S
San Francisco	37 40	123 36	”			55.0						58.2										0 06 S
Pt. Carmel	36 25	122 04	Dec.	54.0		55.5		54.0		53.8												0 12 N
Pt. San Luis	35 15	120 58	”	54.3	55.0	55.0	55.0	55.0		54.1												0 13 N
Pt. Sal	34 59	120 47	”	54.1	55.0	55.2	57.0															0 36 S
San Nicholas	33 32	119 59	”				56.4	56.0	56.8	57.0	55.6	57.0										0 37 N
San Diego	32 33	117 28	”	59.8	59.6		59.0		59.9		59.0		58.0	59.6								0 06 S

Width of each column equals 15′ of Longtitude changes to changes due to differences in latitude or to distance from the coast line. In the published records of the observations we are not given the time of the day nor the condition of the weather. According to Buchan's discussion of the Challenger observation, the daily variation of the temperature of the surface of the sea does not exceed 1° F. In general the differences considered in this paper greatly exceed that amount.

The first line of temperatures in the table is but a part of a survey extending from Cape Flattery nearly to Dutch Harbor on the island of Unalaska, made during the latter part of September, 1873. The first temperature near shore was 50.4°. In going westward 120 miles and northward about 40 miles, the temperature increased to 59°. From this point the rest of the survey shows a gradually falling temperature, but the initial temperature of 50° was not again reached until the vessel was nearly 1,000 miles to the westward, about 370 miles north of the starting point and only some 200 miles from the island of Kadiak on the Alaska Coast.

This increase of temperature on first leaving the coast and the subsequent slow decrease are more striking when it is considered that the last records were made two weeks later in the autumn than the first.

The next eight lines of survey represented in the table extend off shore from 100 to 200 miles. Their lengths are shown approximately in the table where each column represents 15′ of longitude. These lines uniformly indicate that the water near shore is colder than that further to the westward along the entire coast from the Straits of Fuca to San Francisco. The lowest temperatures obtained are at Cape Mendocino and Trinidad Head and are at the two stations which are the closest inshore. They are also near the change to the southeast in the direction of the coast line. It is noteworthy that these lowest temperatures are not those found further north. On the contrary, according to the data now at hand, it is more than 500 miles to the northward before surface water as cold as that near the coast between Cape Blanco and Cape Mendocino is reached, during the late summer and the early fall.

Southward of San Francisco the temperatures in the table do not show such marked variations. The first three lines—all north of Point Conception—are in harmony with the existence of an inshore belt of cold water. South of Point Conception there is no evidence of such a cold belt. As indicated in the table the length of the lines south of San Francisco is less than that of those to the north. The Point Sal and the San Nicolas lines also vary greatly from east and west lines.

South of Point Conception, the submarine plateau or continental shelf is much wider; that is, there is a much broader area of comparatively shallow water. This wider continental plateau and the bend in the coast line at Point Conception are probable elements in the causes which determine the absence of a marked inshore belt of cold water off southern California.

The temperatures in the table with those obtained by the Tuscarora in the cable survey from San Diego to Honolulu have been laid off on the coast survey charts; the cable survey temperatures, like the others already considered, give no indication of a cold belt near shore, south of Point Conception. For the first 150 miles from San Diego, the surface temperatures vary from 58° to 59°. Beyond that, the temperature slowly rises as the line runs to the west-southwestward to the Hawaiian Islands.

TEMPERATURE OBSERVATIONS OF THE ALBATROSS.

In 1891-2 two surveys were made by the U. S. S. Albatross, between Monterey Bay and Honolulu—the one on a great circle, the other on a rhumb line. On the great circle line, the surface temperatures for the first 150 miles vary from 54° to 56°. It then rises to 59°, drops to 57°, and rises to 62°. After that it rises slowly as the line runs toward the tropics. The observations on the Monterey end of the survey were made in October, 1891. On the rhumb line in January, 1892, the temperature off Monterey Bay was 52°, rising to 59° in 140 miles. Even with a liberal allowance for the southing made on these lines, the surface temperatures near shore are distinctly lower than further to the westward.

The vertical distribution of temperature on these two lines is shown on the isobathymetrical charts accompanying the report of the survey.* In both cases the isobathytherms in the upper part of the ocean rise on approaching the California Coast. They indicate that water near the surface close inshore is as cold as that 1,000 to 2,000 feet below the surface 200 to 400 miles off shore.

From 1888 to 1900 the Albatross made several series of hydrographic soundings along the Pacific Coast. A line run in September, 1888, off Cape Flattery falls between the first two lines in the table of Tuscarora soundings. The stations are close together and the temperature rises from 52° to 61° in running off shore about 50 miles and in the next 30 miles falls, but only to 59°. The inshore cold belt is well marked, for the temperature remains at 52° for the first 20 miles. Southward from Cape Flattery to Cape Mendocino the series of surface temperatures is quite complete but they are usually confined to a coast belt of less than 30 miles in width. They are also scattered through various months in the term of 12 years. For comparison with the Tuscarora observations, temperatures taken during the autumn months have been used. The general result has been to confirm fully the conclusion that a belt of cold surface water exists near shore. Of equal interest is the fact that the temperatures show narrow belts of warm and of cold water lying close together and frequently occurring in the area covered in one day's observations. Usually these narrow belts are at right angles to the coast. This peculiar arrangement of the minor temperature belts seems to negative definitely the idea that the cold coast water is due to an inshore Arctic current, for such a current would give a stream of moderately uniform surface temperature and the variations that did occur would naturally extend in belts or lanes having the same longitudinal direction as the main stream.

As an illustration of the results obtained in charting these temperatures, a section of the coast extending about 150 miles northwest from Cape Blanco is shown in Pl. 31. Close inshore

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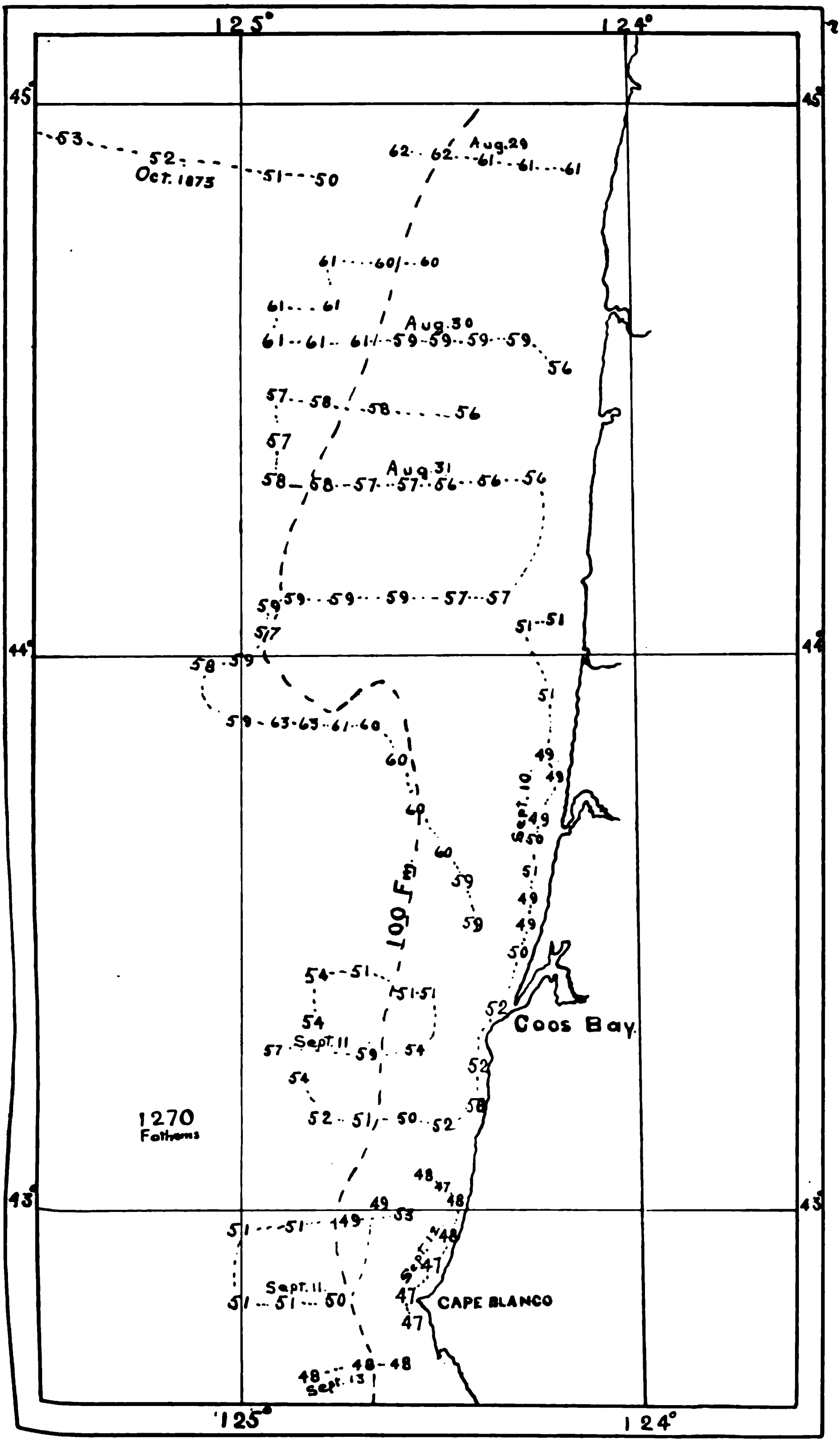
* Senate Ex. Doc. No. 153, 52nd Cong., 1st Ses.



Surface temperatures along a portion of the Oregon Coast for August or September. The 100-fathom line and an occasional deep-water sounding indicate approximately the ocean depths. The dotted lines connect temperature observations made on the same day.

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the temperatures ran from 47° to 52° in the vicinity of Coos Bay from September 10 to 12, 1889, while on the 11th a little further off shore there is a short line running from 57° to 59°. Notice also that on the same day within 10 miles on the north and on the south, there are lines with temperatures varying from 50° to 54°; that is, of the three short lines at right angles to the coast just south of Coos Bay, the middle line averages about 6° warmer than the other lines. Over the Heceta Bank, it will be noticed that temperatures of from 60° to 63° occur, while close inshore a temperature of 49° occurs only ten days later. The ten days' difference in time can cause no appreciable seasonal change in temperature and the variation from 63° to 49° very probably was true for the same day. The lines of temperature for August 30 and 31 are typical in showing the colder water inshore, the exceptions to this rule being few and with slight differences in temperature. No exception has been found with east or west lines of 50 to 200 miles in length and which run close inshore.

INSHORE BELT OF COLD WATER.

This general idea of a cold inshore belt has long been recognized. Richter* discussed the Tuscarora temperatures and called attention to the belt of cold coast water which they indicate. Apparently without other observations he accounted for the presence of this cold water by assuming the existence of a cold surface current from the Arctic. Part of Richter's argument is based on the strange error that "the western coast of the United States trends northeastward from Cape Mendocino to Tatoosh Island," when in fact Tatoosh Island is slightly *west* of north from Cape Mendocino. As already stated, a study of the temperature relations found in Pl. 31 renders highly improbable this idea of a cold polar surface current. Before discussing the hypothesis advanced in the present paper to account for the cold inshore belt, the temperatures for greater areas of the North Pacific should be examined. The temperature charts for the entire west coast give a mass of detail which can be studied best by expressing the figures for a limited period by isothermal lines. In Pl. 32 is given the general result for the month of August.

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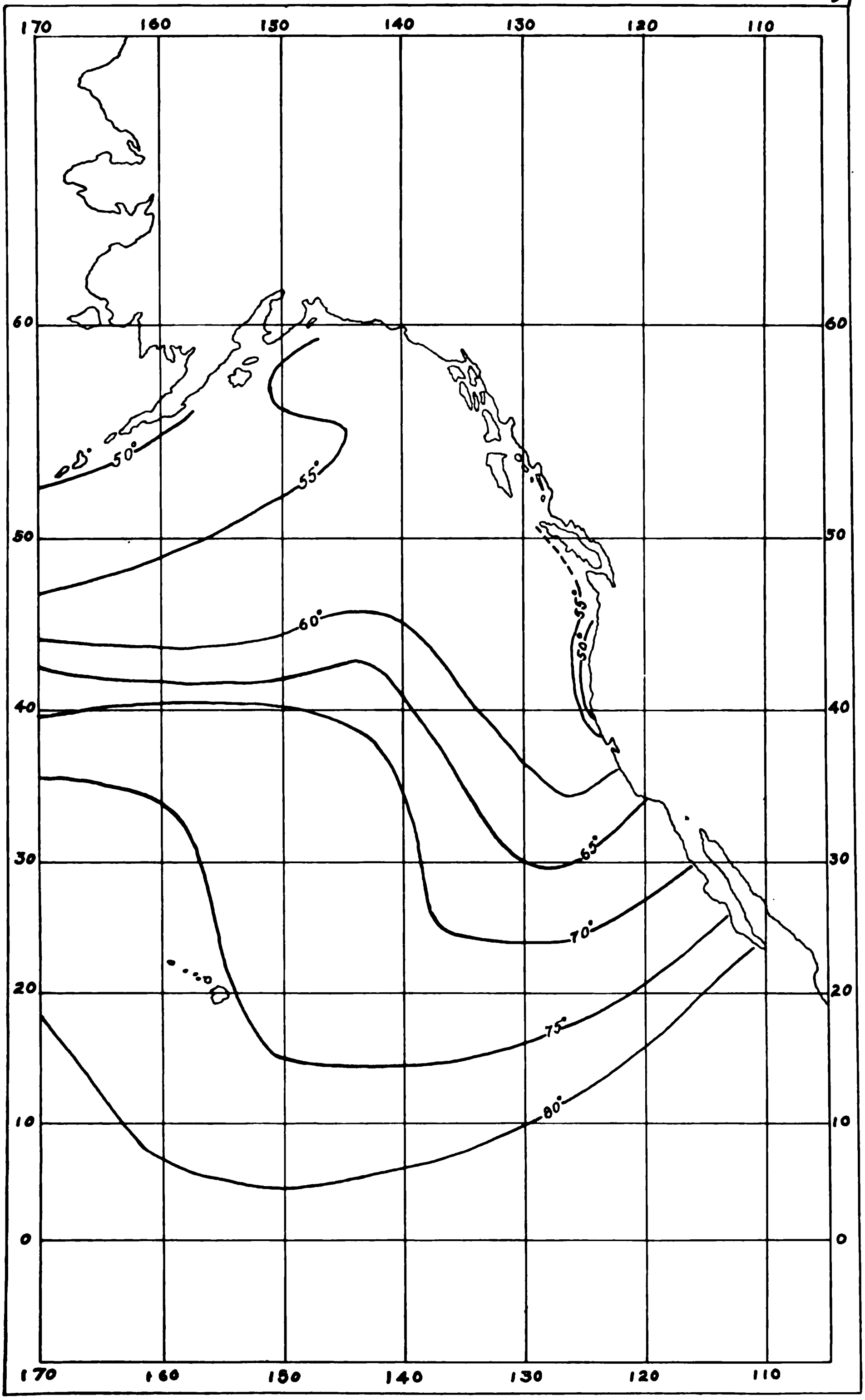
* Richter, C. M. Ocean Currents Contiguous to the Coast of California. Bull. Cal. Acad. Sci., vol. 2, p. 337.

A salient feature of this chart is the area indicating warmer water to the north of the inshore belt of cold water as well as to the west and south. The fact of the presence of this warmer water in addition to the minor belts of varying temperature already shown in Pl. 31 seems to exclude entirely the hypothesis of a cold, polar surface current along the west coast of North America. The only remaining explanation is that there exists a belt of cold water upwelling from the adjacent ocean depths. Possible reasons for this upwelling will be discussed later. A prior consideration is the general trustworthiness and the degree of accuracy of the isotherm in Pl. 32. The writer feels confident that the location of the coldest part of the inshore belt in the vicinity of Cape Blanco and Cape Mendocino and the existence of warmer water to the northward are fully established. The exact position of the isotherms is open to doubt but it is not believed that the error is sufficient to affect the general relations which can be shown on a map of the scale used in Pl. 32. Moreover the problems and conclusions of the paper will not be changed by a future shifting of the boundaries of the temperature zones here represented.

The essential differences between the chart here presented and previous isothermal charts of the North Pacific for the month of August will now be examined. The charts to be cited show little if any variation in the location of the isotherms in mid-ocean, but differ widely in the vicinity of the American Coast. Marakoff in his work already quoted makes the isotherm of 18° C. turn abruptly to the southward at about latitude 45° and again bend to meet the coast in about latitude 36°. He thus represents the cold belt along the coast as merely an extension of the cold zone of the extreme North Pacific. The British Admiralty charts (1886) show the isotherm of 60° as almost touching the coast near the mouth of the Columbia River and then as swinging out and southward, finally meeting the coast



Isothermal chart of the eastern portion of the North Pacific for the month of August. Lines represent approximate mean temperatures for the month.

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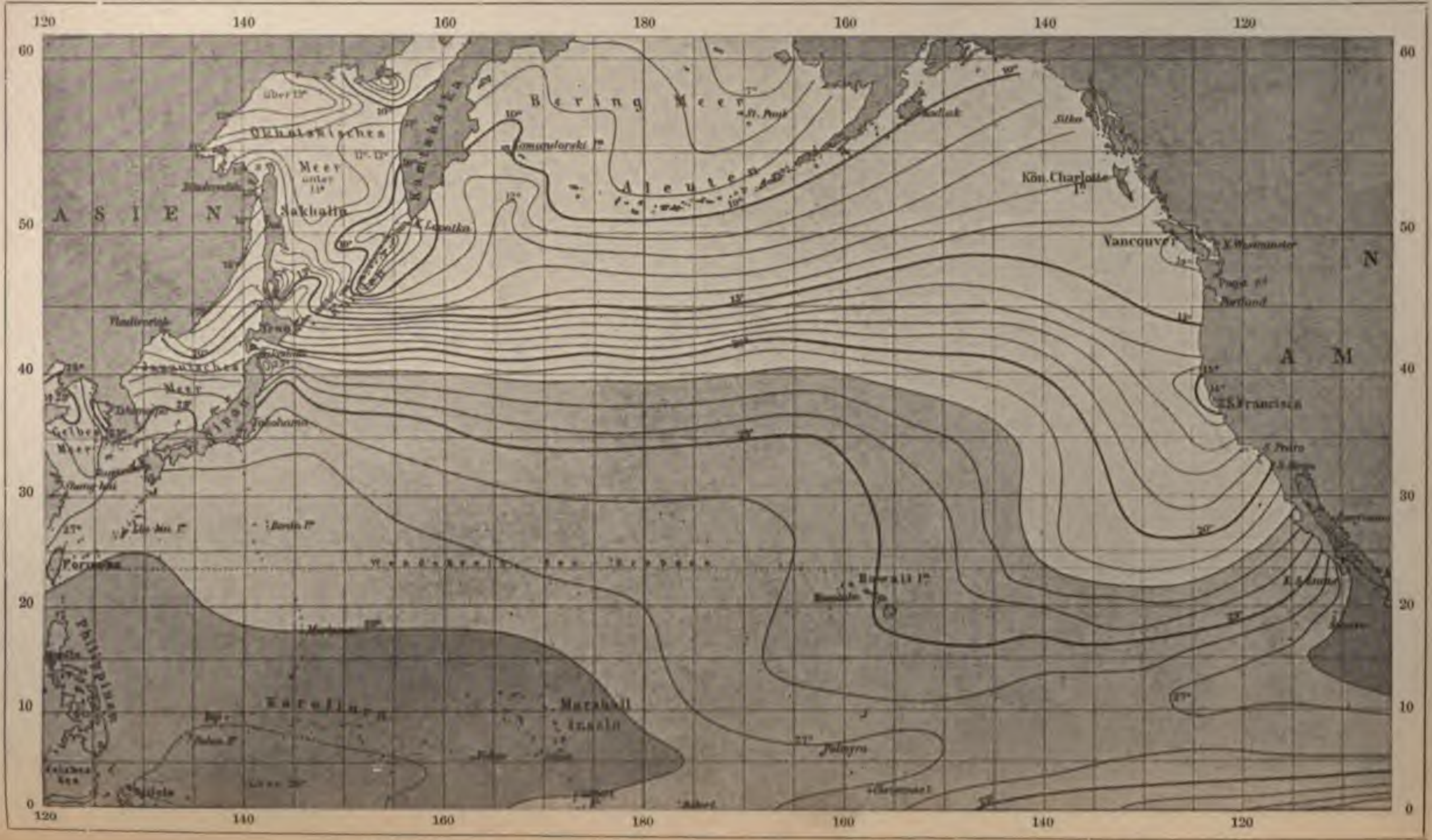

Isothermal Chart of mean August temperatures. Stiller Ozean, Deutsche Seewarte somewhat north of Point Conception. In other words, according to this chart, the belt of cold coast water along California and Oregon has a very narrow connection with the cold water of the extreme North Pacific.

The temperatures for the cold belt are not so low as those reported by the Albatross, but the latter were doubtless taken much closer inshore than those used by the British Admiralty. The locality shown in Pl. 31 just north of Cape Blanco is marked on the British Charts as having a variation exceeding 10° during the month of August. This agrees with the belts of varying temperature found by the Albatross in that vicinity and is probably due to alternate bands of the surface water proper and of upwelling cold water from the ocean depths.

The isotherms of the Deutsche Seewarte chart are reproduced in Pl. 33. They show similar general relations to those indicated in Pl. 32, but differ in making the cold inshore belt much shorter and in locating the coldest part of the belt at two widely separated places—San Francisco Bay and the Straits of Fuca, the lowest temperature being shown by the isotherm of 14° C. (57° F.). The latest data available do not greatly change the average temperatures for these points as marked on the German charts. Davidson[*] gives the monthly averages in the Golden Gate for 12 years of daily observations. The August mean for this period is 59.2°, with 57° the lowest average for any one year. Lower temperatures are reported just outside the bar.

The corrections to be made in Pl. 33, according to the recent Albatross observations, do not consist in a revision of the temperatures given for the cold water areas so much as in the locating of much colder areas near Cape Blanco and in more than doubling the entire length of the belt of cold coast water. The occurrence of the coldest water in the vicinity of Cape Mendocino and Cape Blanco has an important bearing on the theory to be offered to account for the belt of cold water along this coast.

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[*] Davidson, Geo. Bull. Calif. Acad. Sci., Vol. I, p. 354.

TWO PROBLEMS PRESENTED.

The temperature relations of the surface water of the North Pacific represented in Pl. 32 present two problems for solution. First, what is the cause of the belt of cold water along the western coast of the United States? We have already seen that it must be due to an upwelling of cold water from the adjacent ocean depths, but what are the causes which produce this upwelling? And secondly, why should the coldest part of this area be in the vicinity of Cape Blanco and Mendocino, instead of farther to the northward? Before attempting to answer these problems, a brief review will be made of the discussions of cold water in other portions of the world and also of the general temperature relations of the North Pacific.

COLD WATER ALONG OTHER COASTS.

In Pl. 34 A is shown the belts of cold coast water as mapped by Andrees.* Berghaus† gives practically the same areas omitting the southeast coast of Arabia. Both authors make the belt extend along the entire Pacific coast of the United States and of Lower California. Neither of them attempts any differentiation of the cold water area into belts or sections of different temperature. In the handbook accompanying Andrees'‡ Atlas, these areas of cold water are attributed to a vertical current caused by winds blowing off shore and dividing the surface water to the leeward. The supposition is that the accumulation of water to leeward would cause a return drift at the bottom of the ocean and an upwelling near the shore.

A discussion and indorsement of this idea is given by Murray§ as a preface to his study of the effect of winds on the lochs of Scotland. With such small bodies of water as the lochs, the entire surface is under the influence of wind blowing in the same direction and return surface currents are not possible. With the ocean partial compensation may be made in other ways.

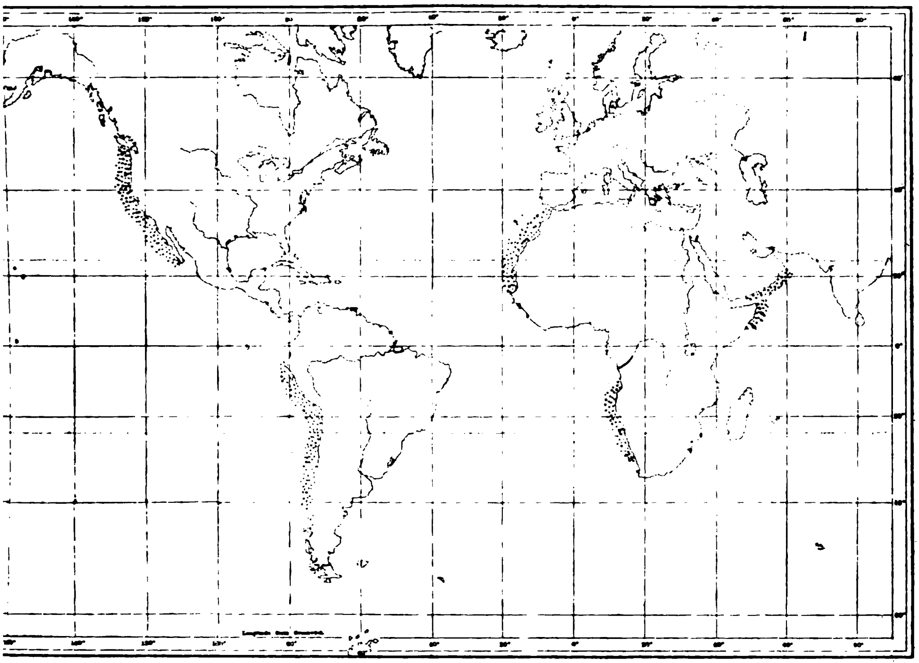
---

* Andrees. Allgemeiner Hand Atlas, 1900.

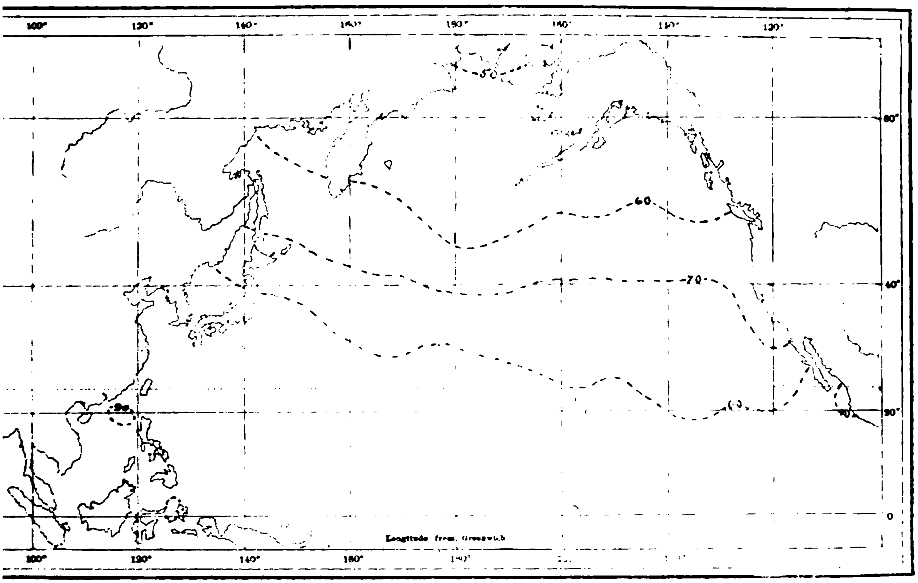
† Berghaus. Atlas der Hydrographie, 1891.

‡ Geographisches Handbuch zu Andrees Handatlas, 1899.

§ Murray, Sir John. Effects of Winds on Distribution of Temperature, etc. Scot. Geog. Mag., 1898, p. 345.



A. Belts of cold coast water according to Andrees. Compare the West Coast of North America as given here with the same region in Pl. 36.



B. Maximum Surface Temperatures, after Sir John Murray.

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Hann* accepts the theory that the rise of cold water along the coast is caused by the "suction effect" of winds blowing off shore. In his general discussion he incidentally remarks "that the sharp deflection of an ocean current off shore may cause a rise of cold water from below." He does not apply the latter ideas to any of the areas which he discusses, which are substantially those mapped by Andrees. The whole California coast is mentioned among others as if it belonged in the area of constant trade winds.

Buchanan† discusses this subject and gives some data for our coast. During his voyage from Valparaiso to San Francisco in 1885 he stopped at Mazatlan. He states that on getting under way from that port the surface temperature was 75.8° and "the cold water must have been close to the surface, for water taken from the wash when the steamer was going astern had a temperature of 72.8°." Thence across the Gulf of California the temperature was 78° and the water a deep blue color. Approaching Cape San Lucas the temperature of the water fell to 73.4° and then to 64.4° close inshore. After passing the Cape the temperature rose to 66.8° as the shore was left. Thence northward to San Francisco the water grew colder, falling to 50° degrees at the entrance to the bay. The low temperature found in passing Cape San Lucas is the most important part of this account. The cold water he found on the further trip to San Francisco being on a single line parallel to the coast furnishes little basis for discussion. Mr. Buchanan offers the following comment: "The occurrence of these coast areas of abnormally cold water is explained when we recognize that they are the windward shores of the oceans. The trade winds blow from them toward the equator and in so doing mechanically remove water, which has to be supplied from the readiest source. This source is the deep water lying off the continental coast which is supplied by the gradual drift of water from high latitudes. Hence, though the low temperature of the coast water is referred to as due to the cold of high latitudes, it is not supplied by a long surface current, but a short vertical one." The limits of the trade wind belt off the California coast will be discussed later, but it is needless to remark that these limits never reach as far north as Cape Blanco. Mr. Buchanan, it should be noted, does not discuss the conditions on the coast north of San Francisco.

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* Hann, Julius. Handbook of Climatology, 1903.

† Buchanan, J. Y. Similarities in the Physical Geography of the Great Oceans. Pro. Roy. Geog. Soc., 1886, p. 753.

Possibly the most interesting instance of cold water rising from ocean depths is found on the Somali Coast of Africa just south of Cape Guardafui. Captain Hoffmann's account of the voyage of the Möwe is becoming classic in these discussions. The course of the Möwe was northward from Zanzibar along the coast of Africa to the Gulf of Aden. The table of temperatures herewith is taken directly from Captain Hoffmann's account, changing the temperatures to Fahrenheit to agree with the use in this

OBSERVATIONS OF CAPTAIN HOFFMANN

FROM "REISE S. M. KR. MÖWE VON ZANZIBAR NACH ADEN"*

Latitude	Longitude	Date	Hr.	Temp. Water	Latitude	Longitude	Date	Hr.	Temperature Water
		1886 June 28	12	79°.2	4° 41′ N	48° 14′ E	July 3	12	68°.0
		" 28	12	75.2			" 3	4	65.6
4° 42′ S	39° 36′ E	" 29	12	77.7			" 3	8	64.8
		" 29	12	77.0	7 10 N	49 33 E	" 4	12	69.8
1 58 S	41 25 E	" 30	12	79.5			" 4	4	68.4
		" 30	12	77.4			" 4	8	64.2
1 15 N	43 15 E	July 1	12	80.4			" 4	12	66.6
		" 1	12	78.1			" 4	4	66.9
2 35 N	46 24 E	" 2	12	78.8			" 4	8	66.2
		" 2	12	74.8	9 30 N	51 21 E	" 5	12	68.0
4 41 N	48 14 E	" 3	12	77.4			" 5	12	73.9
		" 3	4	71.2			" 5	8	C. Guardafui
		" 3	8	68.0	11 56 N	51 05 E	" 6	12	90.3

---

*Ann. der Hydrogr., 1888. p. 345.

paper. The marked fall in temperature on July 3 and 4 was accompanied by a fall in the temperature of the air and by a change in the color of the water from blue to a deep olive green. As in this locality a cold polar current is an impossibility, unless it persists directly across the equatorial region, we are forced to the conclusion that the cold water rises from the ocean depths. Captain Hoffmann reports a strong north flowing current that makes a bend to seaward at this point where the fall in temperature occurs. He states that the fall in temperature seems to be related to the change in the direction of the current. Buchanan attributes the cold water in this instance to the southwest monsoon blowing off shore. Hann and Andrees do the same and state that the cold water disappears with the coming of the northeast monsoon.

The authorities quoted, with the exception of Captain Hoffmann, seem to be in general agreement in accepting winds blowing off shore as a sufficient explanation of cold coast water in these areas. On our coast from San Francisco to Cape Flattery, the prevailing winds blow toward the shore, as shown in the Pilot Charts. During the passage of an extratropical cyclone,—the "low" of the weather map—the winds may be temporarily reversed. As to trade winds on the California coast, the Pilot Charts for 1903 show that the most northerly extension of the trades—occurring in August—was to Lat. 37° 30′. This was only in mid-ocean nearly 1,000 miles to the westward of San Francisco. Nearer the coast the northern limit of the trades is further to the south. At all seasons of the year the Pilot Charts show a belt of northwest winds between the Southern California Coast and the trade winds. Along Southern California where the trades blowing off shore are the nearest to the coast is the very locality that fails to show a definite belt of cold coast water.

GENERAL TEMPERATURE CONDITIONS OF THE NORTH PACIFIC.

For a brief summary of the temperature conditions of the North Pacific we may take a recent article by that eminent authority, Sir John Murray.* The charts which he gives afford a summary of a vast amount of observational detail bearing on the general problems of his paper. The charts showing maximum and minimum surface temperatures will first be examined. These were prepared by laying off on 2° squares all the recorded observations of surface temperatures. The tables of Admiral Makaroff give 38,874 observations for the North Pacific. Murray has supplemented these by the reports of the British Admiralty Office and from other sources. The maximum and minimum temperatures are taken for the months of August and February respectively. Nearly 25% of the 2° squares in the North Pacific have no recorded observations. This lack should be borne in mind, but as nearly half of these omissions are in the Torrid Zone, it is not likely that the mapping of maximum or August temperatures in the broad belt of these charts has been seriously affected.

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* **Murray, Sir John. On the Temperature of the Floor of the Ocean, etc. Geog. Jour. 1899, XIV, p. 34.**

Maximum Surface Temperatures.—Pl. 34 B shows the results for the North Pacific, the temperature zones indicating difference of 10° F. So far as the problems of this paper are concerned, the most marked departure from east and west boundaries to these zones is found in the belt of 60°–70°. This shows a notable extension southward along the coast of the United States and reveals the belt of cold coast water, confirming the existence of a southward flowing drift off the coast, as shown on the Pilot Charts. The torrid belt of 80°–90° makes a northward extension along the coast of Lower California. This again confirms the Pilot Chart which shows a northwestward flowing current off the Mexican coast.

Minimum Surface Temperatures.—Pl. 35 A is the chart for minimum surface temperatures in the North Pacific. Here again is the southward extension of the cold belt along the western coast of North America. An interesting fact here is the bend to the southward along the 120th meridian showing that the currents from the north leave the shores of America turning to the westward.

Range of Surface Temperatures.—Pl. 35 B is from another chart by Murray from the same data.* The annual range of tem-

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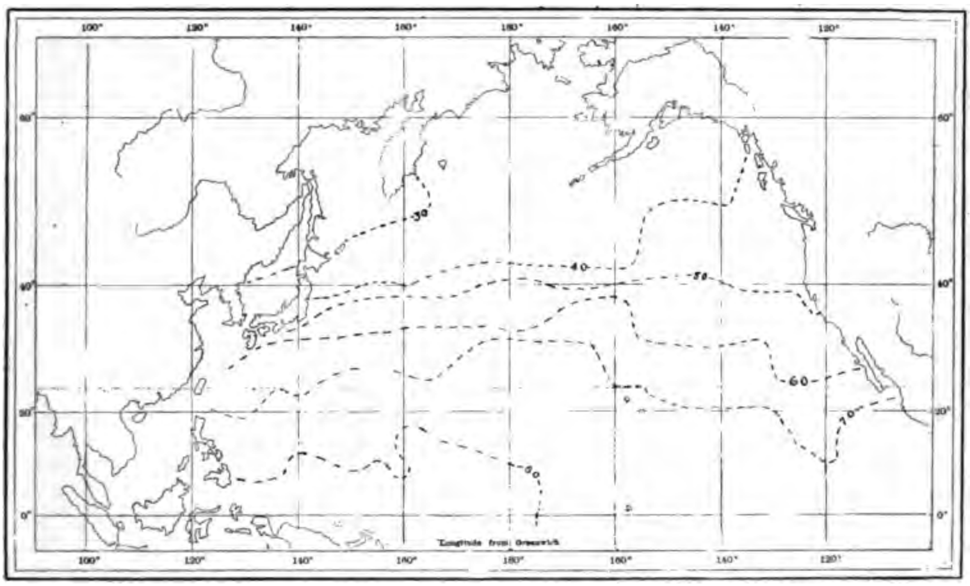
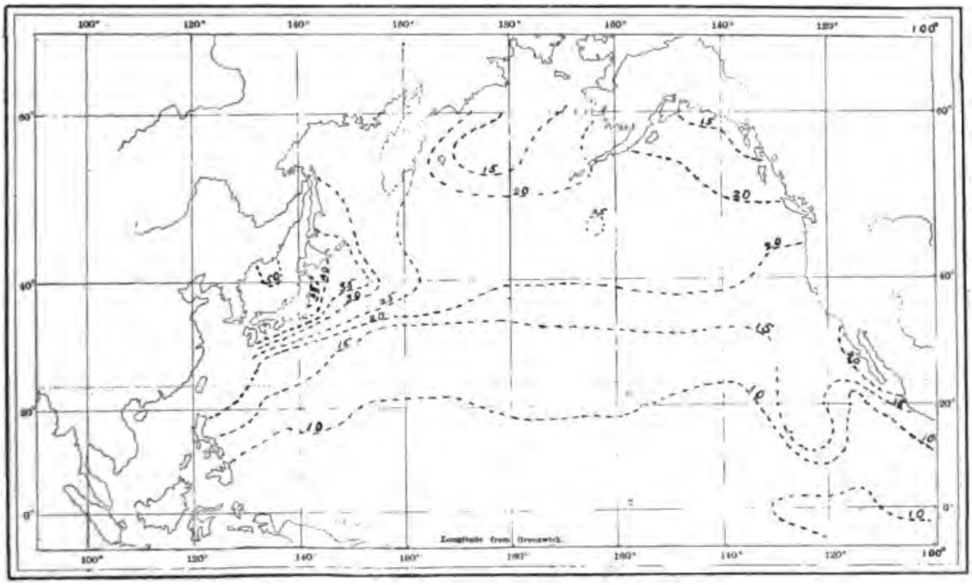
* Murray, Sir John. Annual Range of Temperature, etc. Geog. Jour. 1898, Vol. XII, p. 113.



A. Minimum Surface Temperatures, after Sir John Murray.



B. Annual Range of Surface Temperatures, after Sir John Murray.

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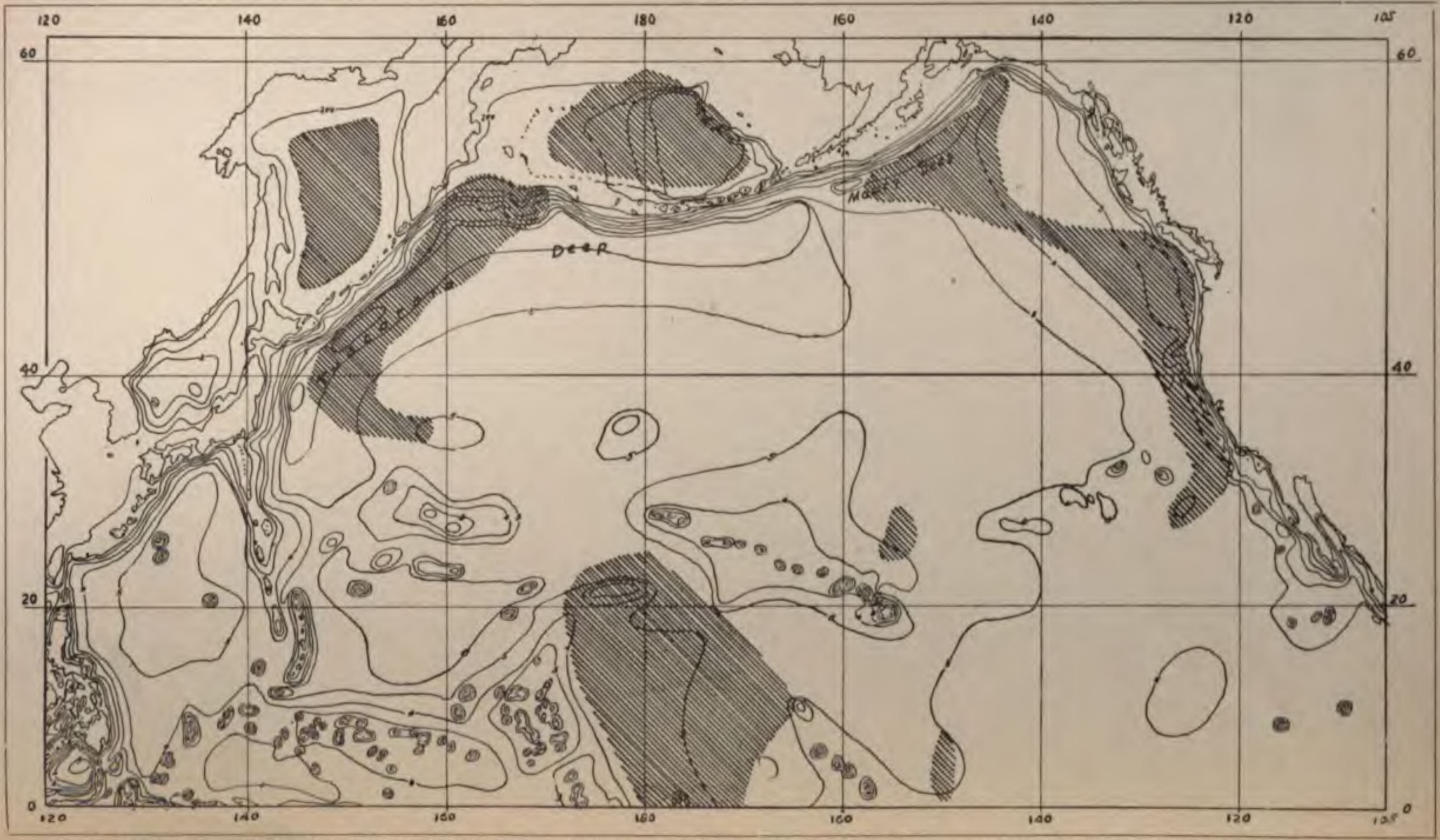

Ocean Depths from Stiller Ozean Deutsche Seewarte. Oblique parallel lines show principal areas with bottom temperature below 35° F., according to Sir John Murray.

perature is here shown. The great torrid belt with an annual range of 10° or less shows a northward pointing extension off Lower California similar to that on the map of maximum temperatures and to be accounted for in the same way. An interesting minor point, bearing on the accuracy of the map, is shown by the small area around the southern part of Lower California, which is charted as having an annual range of 20°. This includes the locality where Buchanan reports cold water due to upwelling. It will be seen by reference to the Pilot Charts that while the main current from the southeast is constant during the year, the inshore current varies with the seasons, sometimes being from the north and sometimes from the south. This variation indicates of course a great annual range of temperature. This mutual confirmation of the two maps in this small area is worth noting as a correlation to the warning given by the authors as to the insufficient data upon which their work rests.

Another variation in Pl. 35 B is the southward extension of the belts of an annual range of from 10° to 15°. This occurs at about 120° West Longitude and extends to Latitude 10°. This is probably accounted for by a variation in the strength of the south flowing California current and of the northwest flowing current off Mexico. This variation is somewhat indefinitely shown on the Pilot Charts by a change in the extension of these currents during the spring and the autumn seasons.

Temperature of Ocean Bottom.—Pl. 36 is a reproduction of the Deutsche Seewarte chart showing ocean depths in the North Pacific. The principal areas which according to Murray have a bottom temperature of under 35° are indicated by oblique parallel lines.

The contours on this chart are in meters; the first line indicating 200 m. and the others the successive even thousands. In the region to the eastward of Kamchatka these contours must be modified to agree with recent soundings of the Albatross. A sounding of 5,700 M. (3,117 Fm.) was obtained in Lat. 54°-51′, Long. 163°-46′ E and other soundings indicate that a channel of about 3,000 M. (1,640 Fm.) leads from the Pacific into Bering Sea. A dotted line shows the possible location of the 3,000 M.

contour according to these late soundings. The distribution of these areas of cold water on the ocean bottom is closely related to the question of the source of the cold water along the west coast of the United States. Of primary interest is the larger area extending from near Alaska southward far beyond Point Conception. The part of this mass of cold water lying north of Lat. 50° is bounded on the north and east by the contour line of 2,000 fathoms (nearly 4,000 M.). The western extension of this mass of cold and presumably heavy water lies just on the edge or slope of a submarine valley that runs down to a depth of more than 3,000 fathoms (6,000 M.). If the distribution of cold water in the ocean depths depends on convection as is frequently claimed, why does not the cold water settle into this deep valley? This might be answered by supposing greater density for the water in the greater depths. A discussion of the varying salinity on the bottom of the ocean in this region is at present impossible from lack of accurate data. The uniform upper level of this mass of cold bottom water is an interesting point when the North Pacific Pilot Charts of this region are examined. In this great bight of the Alaskan coast there is represented an ocean eddy turning contraclockwise for three-fourths of the year and being reversed in direction during the winter months. Is it possible that this eddy maintains a mass of cold water at the bottom at a constant level? The idea of a casual relation here is so seductive that the writer feels compelled, in fairness, to quote a paragraph from the Pilot Chart:—"After a careful consideration of the reports of vessels cruising near the Aleutian Islands and in the Bering Sea, the Hydrographic Office warns mariners against placing too much reliance upon current predictions in that portion of the North Pacific." The warning is probably intended to apply to regions farther to the westward, but should be considered for this region as well. In connection with the question of the existence of this Alaska eddy, it is to be remarked that the isotherm of 55° bends to westward just south of Alaska in a way to confirm the existence of such an eddy. (See Pl. 32.) Setting aside theories and keeping in mind the thought of the level upper limit of the cold bottom water as mapped by Murray for the region south of Alaska, let us examine its great southward extension.

From off Vancouver Island to San Francisco it has risen above the 2,000 Fm. (4,000 M.) contour and lies upon the continental slope of the ocean bottom—again in defiance of gravity unless there is postulated a peculiar arrangement of salinity in the lower depths.

HYPOTHESIS ACCOUNTING FOR COLD WATER BELT.

To explain this apparently abnormal position of the cold water, let us suppose, as a working hypothesis, that the direction of ocean drift in the northeastern parts of the North Pacific is not merely true for the surface, but that it holds throughout the entire extent as far as the ocean bottom. In winter the cold surface water to the south of the Aleutian Islands would sink and at the same time be carried slowly toward the eastward. It would thus be carried over the western portion of the Maury Deep of Pl. 36 and would finally rest on the continental slope. In the Alaska Bight it is conceivable that the eddy would give a constant upper level to this mass of water. To the southward along the coast of Vancouver to San Francisco, the upper drift (except very close inshore) is toward the east and south. If this drift extends to the ocean bottom, the cold bottom water would be driven up the continental slope, thus accounting for the belt of cold coast water. Again it will be remembered that the coldest coast water was found from the vicinity of Cape Blanco southward to Cape Mendocino. In Pl. 36 the contours of 1,000, 2,000, and 3,000 meters make a shoreward bend slightly north of this latitude. That is, a great submarine valley heads just under Cape Blanco and opens broadly out to the northward and westward. The bottom drift on our working hypothesis would thus be delivered most strongly against the coast in the vicinity of Cape Blanco and carried southward by the general drift.

The effect of the smaller submarine valleys near the coast has already been discussed by Davidson.* Speaking of those near Cape Mendocino he says: "They carry in the colder waters coming from the north and outside of the influence of the close inshore eddy current setting to the northward."

The writer fully agrees with this statement, but in the light of the additional data discussed in this paper, he considers the action of these valleys as but part of a general motion of the deeper waters which affects the entire coast from San Francisco to Vancouver Island.

Another instance where local temperatures seem to be influenced by submarine valleys is found on Cordell Bank about 50 miles west-northwest from San Francisco and directly west of Point Reyes. The 100 Fm. contour shows a valley opening to the northward and heading just east of the Cordell Bank. From June 12 to 17, 1873, Davidson† reports the mean water temperature at 8 a.m. as only 49°. If the cold bottom water in the deeper ocean has any motion or drift, it is not difficult to recognize the fact that the submarine valley to the northward might lead it to the surface in the vicinity of Cordell Bank.

A second point in favor of the theory of great depth to the prevailing drift in the northeastern part of the North Pacific is found in the shape of the areas of cold bottom water and in their relation to the surface drift. The main area on the west coast of North America has a longitudinal extension that agrees with the prevailing surface drift. Tracing this area of cold bottom water southward to Lat. 30°, it is seen to bend to the southwestward as do the surface currents. The question also arises as to the reason for a termination of the cold water at this locality. It is certainly not the insolation received in the torrid zone, for this penetrates but a short distance below the surface of the ocean. Moreover, in the middle of the North Pacific extending across the equator into the southern hemisphere is one of the largest areas of water below 35° on the ocean bottom. A ready explanation for the termination of the cold bottom water off Lower California is found in the northwest flowing warm Mexican current previously mentioned. This current, according to the charts of the Deutsche Seewarte, is more saline and hence will sink and mingle with the colder water from the northward.

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* Davidson, Geo. The Submerged Valleys of the Coast of California, etc. Pro. Calif. Acad. Sci., Geol. Vol. I, p. 99.

† Davidson, Geo. Pacific Coast Pilot, p. 236.

Another interesting area of cold water on the ocean bottom is found off Japan in the great Tuscarora Deep. The source of this cold water is doubtless the cold polar current coming down by Kamchatka. The southern part of this cold water area has an extension off to the eastward. It has a direction that appears to be the resultant of a conflict between the deep part of the north-flowing Japan stream and the cold water of the Kamchatka current. Here again the idea of great depth of drift would account for the fact that we have represented a stationary body of cold water resting on the sloping ocean bottom.

Of course, the hypothesis that these ocean currents and drifts have a uniform direction to the bottom of the sea needs additional evidence in its support. Meanwhile it offers a reasonable explanation of the cold coast water on the North American shore and of several peculiarities of the masses of very cold water on the bottom of the North Pacific with little indirect opposition to the hypothesis.

The presence of the large area of cold water on the bottom of the south central portion of the North Pacific here challenges attention. Can it be accounted for by the known direction of surface or bottom drift? It must have some connection with the cold water of high latitudes to maintain its low temperature of 35° or under. There is no evidence to connect it with the cold water off North America. From its position in equatorial regions it must necessarily be supplied by subsurface currents. There are few charts showing temperature below the surface in the North Pacific. Turning to one by Makaroff* for the level 400 meters (218 Fm.) below the surface, the isotherms are found to make a sharp bend to the southeast as may be seen in Pl. 37. This indicates a southeast flowing portion of the cold Kamchatka current which has underrun the warm Japan stream. The writer attempted to construct an isothermal chart for the depth of 700 Fm. in order to follow further this cold undercurrent. The number of temperature observations for this or greater depths is few, and therefore not much reliance can be placed in the results. The isotherms as drawn for the 700 Fm. level show a narrow loop extending still farther to the southeast than the loop in Pl. 37. It would thus seem from the evidence now at hand that the cold water at the bottom of the south central portion of the North Pacific is accounted for by a branch of the Kamchatka current underrunning the upper portion of the warm Japan stream and slowly sinking to the bed of the ocean.

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* Makaroff, S. Le Vitiaz et L'Ocean Pacifique.

In the provisional isothermal chart drawn for the depth of 700 Fm. a second narrow loop of the isotherms, starting farther to the east of the Japan Islands, runs southeast toward the Hawaiian Islands. This would account for the presence of water below 35° F. that occurs to the northward of these islands at the depth of 2,500 Fm.

The study of the areas of cold water at the bottom of the central portion of the North Pacific does not therefore in any way contradict the hypothesis used for the cold water belt along the west coast of the United States. In the northwest due to the opening into Bering Sea between Kamchatka and the Aleutian Islands, a southward flowing cold current disturbs the otherwise great uniform clockwise drift of the North Pacific. In the north central and northeastern portions of the ocean there are no cold currents from Bering Sea to interrupt the acquirement of a uniform direction of drift to great depths.

The possibility of water at a great depth acquiring a slow movement or drift from the action of surface winds has been frequently discussed. A recent writer* thinks that the entire body of water occupying the equatorial regions has a westerly motion due to the action of the trade winds. In the northern parts of the Pacific in the region of the prevailing westerlies, contrary currents are frequently reported more or less in harmony with variations in the winds. But as the prevailing westerlies have existed for untold ages, there has been ample

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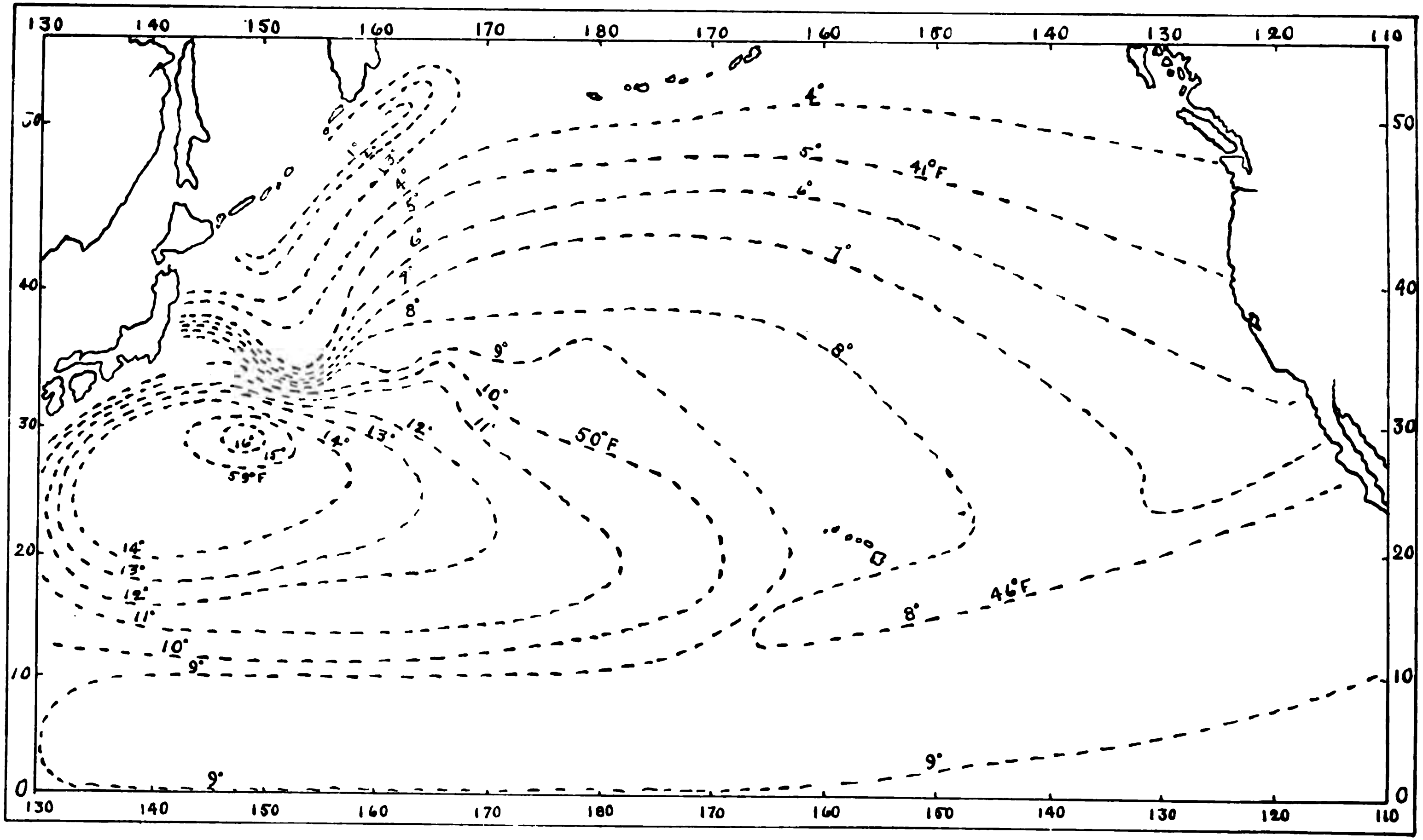
* Page, James. National Geographic Magazine, 1902, pp. 135-142.



Isotherms of the North Pacific at the depth of 400 meters, temperatures in centigrade degrees. After **Makaroff.**

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time for the development of a slow but constant deep water movement in the direction of the prevailing wind. The northeastern part of the North Pacific is pre-eminently the place for the development of a uniform drift from surface to bottom, as may be seen by studying the contours in Pl. 36. The contours show a remarkable great ocean basin uninterrupted by islands and bounded on the north and east by a regular but steep continental slope. This regularity of basin of the North Pacific is more noticeable if for comparison we examine a bathymetrical chart of the North Atlantic. In the latter we have the mid-Atlantic ridge running in a general north and south direction and making two great subdivisions of the basin. We have also the wide openings on the west and on the east of Greenland and connecting with the cold water of the Arctic Ocean. In the Pacific there is but one great opening into Bering Sea and that sea is connected with the Arctic by Bering Strait, which is both narrow and shallow. Considering then its practical lack of connection with the Arctic Ocean and its uninterrupted basin and relatively regular shores, it is a reasonable supposition that the northern half of the North Pacific has a more regular system of oceanic circulation than has the North Atlantic.

SUMMARY.

Several interesting points for future investigation are suggested by the observations and theories discussed in this paper. From the biological standpoint it will be interesting to find whether the cold water and the variations in temperature near Cape Blanco are a barrier to species that might normally expand into the regions lying to the northward. The investigation of the area lying to the southwest of the coast from Point Conception to San Diego, now being carried on under the direction of Professor William E. Ritter of the University of California, should in the next few years give us more accurate information concerning the disputed temperature relations of this portion of the Pacific as well as a better knowledge of the marine life of the region and the temperature limitations of this life.

The question of the accuracy of the charts herewith presented demands that the various gaps in the series of coast temperatures be filled by reliable observations. If the theory of this paper as to the final source of cold water lying along the west coast be correct, serial temperatures in the region from 50° to 55° N. Lat. and about 160° W. Long. should show, at certain seasons of the year, inversions of temperature, that is, a stratum of cold water should be found in intermediate depths overlying warmer water on the ocean bottom.

In conclusion the following summary of observations and hypotheses in reference to the belt of relatively cold water lying along the west coast of the United States is presented:

(1) Recent observations indicate that the previous mapping of this cold belt as extending southward to the coast of Lower California is incorrect. The definite belt of cold water can not be traced south of Point Conception.

(2) In summer the coldest part of this belt is in the vicinity of Cape Blanco and Cape Mendocino.

(3) The source of this cold coast water is in the ocean depths to the northwestward.

(4) This cold water at or near the ocean bottom has a slow drift agreeing in direction with the average direction of the surface drift and is driven to the surface on striking the slope of the continental shelf. Local variations in the cold coast water are due to the submarine valleys and other irregularities in the slope of the continental shelf.

University of California,
September, 1905.

UNIVERSITY OF CALIFORNIA PUBLICATIONS
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Vol. 4, No. 14, pp. 287-357 ANDREW C. LAWSON, Editor

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BY

ANDREW C. LAWSON.

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INTRODUCTION.

The Egan Range is one of the larger members of the Basin Range system of mountains traversing eastern Nevada with a general north and south trend. The range has a breadth of several miles and is separated from the neighboring parallel ranges by broad, flat, alluvial valleys coextensive with the ranges between which they lie. The chief formations which enter into the structure of the range are, so far as at present known, sedimentary strata ranging in age from the Cambrian to the Carboniferous. These strata have an aggregate thickness of many thousands of feet, and the entire sequence has been compressed in part into open, fairly symmetrical, folds, which locally may be more acutely appressed and affected by dislocations. The pre-Cambrian basement upon which the Palaeozoic rocks rest is not exposed; but, at various places in the range, there are intrusive masses of granitic and monzonitic rocks and some of these have been supposed erroneously to represent the Archaean. It is probable that these granitic rocks date from the mid-Mesozoic revolution, which affected the Cordilleran region from the Wasatch to the Pacific, although it is only positively known that they are post-Carboniferous. These intrusions would thus be contemporaneous, in a general way, with the granites of the

Sierra Nevada, the Humboldt Mountains,* the Wasatch,† Central Idaho,‡ and the Coast of British Columbia.§

At a later date, probably in Tertiary time, there were local intrusions of a light colored, acid, porphyritic rock which has since been much kaolinized and silicified, in which or in connection with which important ore bodies are now found. While there is thus a certain degree of complexity of geological structure within the range, the structural lines seem to have had little or no influence in determining either the east or the west border of the range, both of which are remarkably linear, and would appear, from a very partial and cursory examination, to cut obliquely across various structures indifferently, a fact which in itself justifies the conception of the range as an orographic block of the Basin Range type. This independence of the bordering lines of the range to the structure is in marked contrast with the control which has been exercised by the structure upon the geomorphic development within the range. Here the geomorphic expression is conditioned by the structure, and by the differential resistance of the rocks to erosion. In the softer formations the valleys are broad and the slopes are quite mature. In the harder formations the streams run in cañons. In general the montaine geomorphy is much more advanced than in the case of the ranges of the same structural type recently described by Louderback|| in the western part of Nevada, a contrast which may be due, perhaps wholly and certainly in part, to the absence of a cap of basaltic lava in the Egan Range. After the geomorphy of the range had been well advanced toward its present condition there were local volcanic eruptions which caused some of the valleys to be occupied to a limited extent with tuffs and flows of lava. Since then the range has been faulted and a considerable proportion of these lavas and tuffs has been removed by erosion, and the valleys have been deepened below the floors upon which the volcanic rocks rest.

The Robinson Mining district, with the geology of which this

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* Louderback, G. D. Basin Range structure of the Humboldt Region Bull. G. S. A., Vol. 15, pp. 289-346, 1904.

† Emmons, S. F. Am. Jour. Sci., 4th ser. Vol. XVI, pp. 139-147, 1903.

‡ Lindgren, W. 20th Ann. Rpt. U. S. G. S., Pt. III, pp. 65-256.

§ Dawson, G. M. Geol. Surv. Canada Ann. Rpt., 1886, Pt. B.

|| *Op. cit.*

paper deals, is but a very limited portion of the Egan Range. It lies in a pass through the range a few miles southwest of the town of Ely. The district comprises a belt varying little from a mile in width and having a length of about six miles. This belt has an east and west trend and thus lies transverse to the general course of the range. The mineralization of the district which gives it its economic importance is intimately and genetically connected with an irregular intrusion of "porphyry" cutting Carboniferous rocks and occupying the center of the belt. Ore deposits are found both in this porphyry mass and in the sedimentary rocks which border it. In the porphyry itself are found copper ores in large quantity. In the limestones on the northern flank of the porphyry zone, particularly toward its eastern end, are limited bodies of lead ores carrying some silver; and on the southern flank, also at the eastern end of the belt, occur gold ores in ledges in the sedimentary rocks. The silver lead ores have as yet not been found in sufficiently large bodies to warrant permanent mining operations, although considerable prospecting has been done and some ore has been shipped. The gold ores at the Chainman and Saxton mines have attracted the attention of capital sufficient for the erection of extensive and costly plants for their reduction, but the attempt to win the gold has been apparently unsuccessful and both plants are now* idle. The chief interest in the district now centers in the copper deposits which give much promise of being mined on a large scale in the near future. The chief localities in the district where these ores have been developed by mining operations on a notable scale are at the Ruth Mine in the eastern part of the belt, at Copper Flat in the middle, and in the vicinity of Pilot Knob at the west end. Besides these, however, there are numerous prospects and mining locations throughout the district.

In the following account of the geology of the district, its limits will be assumed for purposes of description to be coterminous with those of the geological map which accompanies this paper.† The topographic base of the map upon which the geological formations are delineated was surveyed and drawn by Mr.

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* 1905.

† While this paper was passing through the press the map was destroyed in the San Francisco fire. It may be reconstructed and issued later.—ED.

F. S. Schmidt. The contours were sketched with the aid of as many control points, established by transit and stadia survey, as could be obtained in a somewhat limited time. The survey plats of the numerous mining locations and traverses of the roads constitute the chief frame work of the map. The altitudes are approximate only, the nearest reliable bench mark being at Eureka, some eighty-odd miles distant by wagon road, and the only check to this being by aneroid. In relief the district has a hypsometric range of about 1,600 feet, the extremes of altitude being 6,440 and 8,040 at the east end of the district. For topographic details reference must be made to the map. For the purpose of locating observations the mining claims named upon the map will be freely used. The field was geologically surveyed and the map constructed primarily for the purpose of studying the conditions of occurrence of the copper ores, and of delimiting the copper bearing formation. Attention in the field being thus focussed upon a special problem, many phases of the general geology received but incidental or hurried study; it thus happens that, in the attempt to compile the observations into a consistent account of the geology, some questions have arisen for the answer to which the data at hand are insufficient. Notwithstanding this, the study has been sufficiently instructive to the writer to warrant his thus attempting to set forth the results obtained as a contribution to the geology of Nevada and to the problem of the genesis of copper ores.

The literature of the Egan Range is rather scant. In the Report of the Geological Exploration of the 40th Parallel, Vol. II, pp. 486–489, is a brief note by Emmons on the general features of the range based on observations made at its northern end. In Bulletin 208 of the United States Geological Survey, pp. 47–54, Spurr gives a somewhat more extended note on the geology of the range. The only reference to the Robinson Mining district, however, is a paragraph in the work just referred to in which Spurr says: "At Mineral City, just west of Ely, lead, silver, and gold, with some copper, are obtained. At this locality a number of siliceous dykes cut up through the limestone, and seem to be connected with the mineralization. In the neighborhood of Ely there are considerable ore deposits."

THE PALAEOZOIC ROCKS.

The sedimentary rocks of the Robinson Mining District are confined to the Palaeozoic. The upper portion of the section has been determined on palaeontological evidence to be of Carboniferous age. In the study of the structure of the district it has been found convenient to subdivide this Carboniferous series into three formations and for these local names are used. The lower part of the section has yielded no fossils, but falls into two strongly contrasted members, and these, on the basis petrographic and other considerations to be mentioned later, are correlated with the two divisions of the Devonian recognized elsewhere in the basin ranges, viz: the White Pine shale and the Nevada limestone, and they will therefore be described under these names.

THE CARBONIFEROUS.

The Ruth Limestone.—The highest member of the Carboniferous series is the Ruth limestone, a formation of heavy, but distinctly bedded, blue gray limestone, carrying Upper Carboniferous fossils. This formation is characterized by an abundance of flint or chert nodules and the fossils are to a large extent replaced by such silica. The chert nodules are often several feet in length, but generally they range in size from about an inch to a foot in length. A very common form is oval or nearly circular in random cross sections. The color of the chert is much darker than the limestone in which it is imbedded. The rock is otherwise remarkably free from impurities, weathers to a dull gray color and forms but a scant regolith.* The outcrops are usually abrupt and the ridge tops are bare. This formation being at the top of the local geological column and its upper limit being determined by erosion, its full thickness can not be here ascertained. There remains of it, however, not less than 500 feet.

A specimen of the chert from the Ruth limestone showing a laminated structure was particularly studied. It consists of blue-gray chert in layers from 3 to 6 mm. thick alternating with thinner layers of limestone which on weathered surfaces are etched out. The layers or laminae are distinctly curved. In thin section the alternating laminae are distinct (the limestone being turbid from impurities and the chert clear. The line between the chert and limestone is sharp but is irregular. The chert is a crypto-crystalline aggregate of quartz grains showing aggregate polarization effects. There are some shred-like areas of calcite in the chert layers. The limestone is an allotriomorphic granular aggregate of calcite grains of rather vague boundaries. There is an abundance of fragments of organisms both in the limestone and in the chert layers. These organisms appear to be chiefly foraminifera. In the chert the cavities of the organisms are filled with an aggregate of quartz grains of much larger size than those composing the chert matrix, but the chamber walls are still composed of calcite. The same statements are true of the organic remains in the limestone, but silicification of the cavities is less pronounced. In several cases chambered shells were found partly in the limestone and partly in the chert but the character of the shells appeared to be the same for both parts.

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* Merrill, G. P. Rocks, Rock-Weathering and Soils, 1897, p. 299.

Fossils.—The time at the disposal of the writer while in the Robinson district did not permit of a deliberate search for palaeontological evidence of the age of the formations, but wherever fossils were observed in the course of the stratigraphic work they were collected. The localities at which such fossils were found are chiefly confined to the Ruth limestone. These were submitted to Mr. George H. Girty, the well known specialist on the Carboniferous who kindly identified the following forms:

Fusulina cylindrica.
Zaphrentis sp.
Stenopora sp.
Productus aff. *P. porrectus* Kut.
Fusulina elongata (?)
Seminula subtilita.
Lithostrotion mammillare (?)
Diphyphyllum n. sp.
Lonsdaleia n. sp.
Lonsdaleia n. sp. var.

Of this fauna Mr. Girty states that it belongs in the Upper Carboniferous and rather well up. While some of the forms possess more satisfactory evidence than others, he feels little doubt with regard to any. The most dubious as to age in his opinion is the *Diphyphyllum* n. sp., and even in this case he believes that it may safely be regarded as Upper Carboniferous or Pennsylvanian. All of these fossils occur in the same stratigraphically continuous area of the Ruth limestone, of which Fossil Hill is the most prominent feature, on the south side of the Ruth Mine. The *Seminula subtilita* appears to be the most common. The *Diphyphylum* n. sp. also occurs on the Phenix claim in the area of Ruth limestone two-thirds of a mile to the north of the Ruth Mine. It is interesting and satisfactory to observe that the palaeontological determination of the age of the Ruth limestone by Mr. Girty entirely agrees with the conclusions that had been reached by a comparison of the physical characteristics and stratigraphic sequence of the Ruth section with those of the standard section established at Eureka some 80 miles distant.*

The Arcturus Limestone.—Below the Ruth limestone is a strongly contrasted formation of argillaceous, and in part sandy, limestone which may be designated the Arcturus shaly limestone, although the shaly character is not always apparent. This formation is easily distinguished from the other formations of the district by the abundance and yellow color of its regolith. In general it yields to atmospheric erosion smooth slopes strewn with small subangular or rounded residual fragments of yellow limestone. In it there are occasional beds of a massive character, but even these do not project prominently above the general slope. Some of the limestone beds contain a notable proportion of manganese, and when freshly broken present a faint pinkish tint suggestive of rhodochrosite. This formation increases in thickness from east to west, and passes in the country to the northwest of Ruth into yellow, orange and red weathering, soft shales, with thin beds of impure limestone. The formation carries Carboniferous fossils but not so abundantly as the Ruth limestone. Species of *Zaphrentis* and *Stenopora* were recognized by Mr. G. H. Girty. Its average thickness within the district is about 1,000 feet with a minimum of 900 feet in its more eastern exposures.

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* Hague, A. U. S. G. S., Monograph XX, 1892.

The Ely Limestone.—Beneath this formation is the Ely limestone, consisting of regularly stratified, thick-bedded, more or less cherty limestone to a thickness of about 1,500 feet. Its regolith is scant, the weathered surfaces are often of a light lilac gray color, and it forms the boldest bluffs, the most precipitous slopes and the highest summits of the district. It also carries Carboniferous fossils, but the only forms identified by Mr. Girty to whom they were submitted are crinoidal fragments and *Productus* aff. *P. porrectus* Kut.

THE DEVONIAN.

The White Pine Shale.—Below the Ely limestone are formations of supposed Devonian age. The first of these in descending order is a body of shale of somewhat varied character. A good deal of it is ordinary, blue-black, argillaceous shale. Most of the formation is, however, rather siliceous and yields a regolith filled with flat, angular rock chips, which have a yellowish color. Certain portions of the formation, as for example, to the north and northwest of Copper Flat and in the vicinity of Pilot Knob, are carbonaceous and have a dead black color. In other cases, as in the vicinity of the Chainman Mine and Pilot Knob, the rock while having an evenly and thinly laminated shaly structure is almost wholly quartzose in composition. In several portions of the shale belt, the shale has been bleached to a snow white or a cream white color, due, it is presumed, to the action of emanations from neighboring irruptive rocks, or more probably of sulphuric acid arising from oxidation of the overlying pyritiferous porphyry. Some of these have a chalky consistency. A chemical examination of two samples of this bleached shale from the gulch to the east of Jupiter Ridge was made for the writer by Mr. Herbert Ross of the Ruth Mine with the following results:

	I.	II.
SiO_2	65.0	67.1
Al_2O_3	28.5	28.1
CaO	1.8	1.0
H_2O	5.1	3.7
	100.4	99.9

The formation to the northwest of Pilot Knob is traversed by a heavy bed of light gray limestone about 150 feet thick, the shale above and below it being not essentially different. The total thickness of the shale is about 850 feet or with the included limestone bed about 1,000 feet.

This shale formation, with its included limestone bed, agrees well with the descriptions that have been given by Hague[*] for the White Pine shale of the neighboring White Pine and Diamond Ranges to the west of the Egan Range, and it is, therefore, tentatively correlated with that. This correlation is, moreover, sustained by the fact that no other formation of similar character has been described, so far as the writer is aware, from the Basin Ranges for this portion of the geological scale. As the White Pine shale is a fairly persistent formation in the ranges to the west, it is quite probable that it should extend into the Egan Range. Even the thick bed of limestone in the midst of the shale has its analogue in the White Pine shale of the Eureka and White Pine sections.[†] There is one lack of agreement between the Eureka section and the one here described which seems to militate against the correlation suggested, and that is the absence at the Robinson Mining District of the Diamond Peak quartzite. At Eureka this formation has a thickness of 3,000 feet and lies immediately above the White Pine shale. It is to be noted, however, that in passing southeastward from Eureka to White Pine, the Diamond Peak quartzite diminishes from 3,000 feet to a few hundred feet,[‡] and that at this rate of diminution of volume it would feather out before reaching the Egan Range.

The Nevada Limestone.—The correlation of the shale formation of the district with the White Pine shale of the Eureka and White Pine sections is the chief justification for suggesting that the next lower formation is the equivalent of the Nevada limestone of the standard section. This formation is a rather massive, gray limestone which agrees in petrographic character with the description of the Nevada limestone; but no fossils were found in it by the writer, doubtless due to the lack of opportunity for systematic search. Some of the beds of this formation are almost black limestone. The thickness of the formation is unknown as only the upper part of it comes within the limits of the country examined. It was estimated, however, that its thickness was not less than 1,000 feet and might be much more.

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[*] U. S. G. S. Mon. XX.

[†] Hague, *Op. Cit.*, p. 193.

[‡] Hague, *Op. cit.*, p. 192.

CORRELATION WITH THE EUREKA SECTION.

For the purpose of comparing the geological column of the district under consideration with that of the Eureka section, the following correlation of all the Palaeozoic formations is suggested:

	ROBINSON MINING DIST.	Feet	EUREKA.	Feet
CARBONIFEROUS	Ruth limestone	500+	Upper Coal Meas.	500
	Arcturus shaly limestone	1,000	Weber Conglomerate	2,000
	Ely limestone	1,500	Lower Coal Meas.	3,800
			Diamond Peak Quartzite	3,000
DEVONIAN	White Pine shale	1,000	White Pine shale	2,000
	Nevada limestone	1,000+	Nevada limestone	6,000

GENERAL STRUCTURE.

In the study of the general geological structural relations of the Robinson Mining District several factors have to be considered. These are: (1) The stratigraphic sequence of the Devonian and Carboniferous formations as above outlined. (2) The flexure of these strata. (3) The relation of the folded strata to the irruptive masses which cut them. (4) The features introduced in the process of mineralization. (5) The lavas and tuffs. (6) The faulting of the region. Having in the previous section described the stratigraphic sequence, we may now conveniently consider that phase of the structure referable to the deformation of the Palaeozoic rocks anterior to the appearance of the irruptive rocks leaving the discussion of the other factors till later.

The dominant feature in the structure of the Palaeozoic rocks is a broad syncline, the axis of which runs nearly north and south, through the Ruth Mine, and pitches northerly at a considerable angle. In the central part of this fold lies the Ruth limestone with synclinal dips at moderately low angles. Flanking the Ruth limestone on either side is the Arcturus shaly limestone dipping under it. Flanking this on both sides is the

Ely limestone dipping beneath it at somewhat steeper angles. As we pass along the southern border of the district as mapped eastward and westward upon the Ely limestone terrane, we pass into the complementary anticlines of the Ruth syncline. That to the east is of so low an arch that it is difficult to determine with precision the direction of its axis. It is probably, however, north-northeast. It may be referred to as the Saxton anticline from the Saxton mine which is situated upon it. That to the west is much more sharply flexed, and the trend of its axis is northwest and southeast, the pitch being to the southeast. It may be called the Rib Hill anticline from the most prominent feature upon it.

In the heart of the Saxton anticline there appears a broad belt of the White Pine shale dipping beneath the Ely limestone on the foothills to the south of the Lane city. On this belt are situated the Saxton and Chainman Mines. Flanking the White Pine shale on the south side of Lane Valley are some areas of limestone the relation of which to the shale is not clear. On petrographical grounds they are mapped as Ruth limestone.

In the Rib Hill anticline, the White Pine shale again appears beneath the Ely limestone, although the direct relationship is largely interrupted by the porphyry of Jogalong Ridge and the monzonite of Weary Flat. The dip of the shale with its included bed of hard limestone beneath the Ely limestone may, however, be clearly observed to the west and northwest of Pilot Knob. In the same anticline, as it broadens out to the north on the north side of Weary Flat, appears the Nevada limestone from beneath the White Pine shale, extending as an important terrane in the hills to the north of the western part of the district.

THE IRRUPTIVE ROCKS.

MONZONITE BATHOLITH.

One of the most interesting features of the geology of the district is the occurrence of an intrusive mass of monzonite. The chief interest attaches to the fact that it appears to be an example of a rather frequent occurrence of plutonic intrusives of granitic habit which have been reported from various parts of the Basin Ranges, and which have generally been referred to the Archaean. In this case the mass is clearly of post-Carboniferous age and there is not wanting evidence that this will be found to be true of many other similar rock masses. The monzonite appears in the Rib Hill anticline and underlies the relatively low and gently sloping ground of Weary Flat in the western part of the district. Its occurrence is marked by no prominent outcrops nor even by hilly ground. The area occupied by it can be delimited with a fair degree of precision. The regolith which thinly veneers it is so characteristic of the underlying rock, that, taken with the occasional exposures of the latter, and the opportunities afforded by the rather numerous prospect holes that have been sunk upon it, particularly about its periphery, there has been no serious difficulty in mapping it. The longest diameter of the area is about one mile in a northeast-southwest direction and its width is about half a mile.

The rock composing the mass is in general a rather coarse grained, pinkish to gray hornblende-monzonite, with large porphyritic crystals of orthoclase, and has a characteristic plutonic habit. When this rock was first met with in a rapid survey of the field to be studied, the writer, relying upon previously reported occurrences of Archaean granitic rocks in the basin ranges, naturally supposed that he had here to deal with the basement upon which the Palaeozoic rocks were laid down. In testing this hypothesis, however, several facts came to light which seemed to be inconsistent with it. It was remarked with surprise that the lower part of the Palaeozoic column, including the Silurian and Cambrian which form voluminous and persistent terranes throughout this part of Nevada, was here absent. The lowest rocks in contact with the monzonite are those referred in this paper to the Devonian. In meeting this objection it was considered barely possible that a pre-Devonian disturbance and erosion interval had removed the earlier Palaeozoic rocks, or that this portion of the region had remained an insular mass in Cambrian and Silurian times and had been finally submerged only with the advent of Devonian time, and that the monzonite might thus still be regarded as a portion of the Archaean floor upon which the Palaeozoic in general was laid down. This possibility was, however, not supported by the facts observed in the course of detailed mapping. It was found for example that there was no trace of a basal conglomerate or even of an arenaceous formation at the contact with the monzonite, such as would have been expected had the Devonian rocks been deposited in a sea transgressing a subsiding Archaean terrane of this character. It was found further that the stratification planes of the rocks nearest to the monzonite were not parallel to the surface of the latter but were in several instances in striking discordance with the locus of contact and appeared to abut directly upon it. It became, moreover, very apparent that the monzonite was in direct contact with quite different and widely separated stratigraphic horizons. For example, the monzonite appears, in quite satisfactory exposures on the west and south sides of Weary Flat, to be in direct contact with both the White Pine shale and the Nevada limestone; and it appears to be transverse to the entire thickness of the first named of these formations. As such observations multiplied, it of course became evident that the original hypothesis was entirely at fault, and its rejection cleared the way for the adoption of the hypothesis that the monzonite is an intrusive mass of later age than the rocks with which it is in contact. The facts which served to overthrow the first hypothesis are quite in harmony with, and indeed, strongly support the second. They do not, however, establish its correctness beyond question; for there is still a third hypothesis with which the same facts are not inconsistent. It is possible that the relations subsisting between the monzonite mass and the sedimentary rocks, in so far as they have been described are due to complex faulting. The monzonite area may be bounded by faults. The absence of the lower part of the Palaeozoic section and of a basal conglomerate, the abutment of the sedimentary beds at widely separated horizons upon the monzonite mass, might all be brought about by faulting. As between these two hypotheses, of intrusion and of faulting, the field evidence distinctly favored the former. At the contact of the monzonite with the White Pine formation the shales are altered to a hard bluish hornfels which is in marked contrast with the shales at a distance from the contact. The limestone of the Nevada formation which is normally a gray fine grained, ordinary sedimentary limestone is converted at the contact with the monzonite into a snow white marble of much coarser texture. At the contact of the monzonite with both shale and limestone there are developed bodies of garnet rock which carries more or less chalcopyrite and which can only be interpreted in a certain sense as a product of contact metamorphism. The monzonite itself, moreover, has its character modified in the immediate vicinity of the contact with the surrounding rocks. At a shaft by the roadside immediately north of the Monarch claim, for example, the monzonite at the contact is much finer grained than at some little distance away, and presents the features of a chilled edge of an intrusive mass. These facts, taken with the others above enumerated, establish the intrusive hypothesis upon a very satisfactory basis; and in the absence of any evidence of faulting leave it unquestioned.

A small isolated area of the monzonite, occupying a few acres upon the Sacramento, Schley and Good Enough claims north of Pilot Knob, is regarded as an integral part of part of the large mass underlying Weary Flat. It is separated from the latter by but a few hundred feet. It cuts both the Nevada limestone and the White Pine shale and has a well exposed contact zone of garnet rock against the limestone. If erosion had cut but a little deeper, the roof of sedimentary rocks in the intervening space would have been removed and the two areas thus shown to be one as indicated in the section C–D on the accompanying geological map.

Just beyond the confines of the map, however, on the Taylor claim, north-northwest of Pilot Knob, there is another area of the monzonite which may similarly be interpreted, or, inasmuch as it cuts considerably higher into the sedimentary rocks, it may be regarded as an apophysis from the same mass. The rock here has more the facies of a quartz monzonite, there being a little quartz present. It has associated with it garnet rock carrying chalcopyrite as shown by prospecting operations. While it is clear that the mass of monzonite of Weary Flat is an intrusive batholith (or possibly laccolith), it seems also certain that the intrusive process was peculiar in certain ways. Usually in the case of plutonic intrusives that the writer has had opportunity of observing there is evidence of greater intensity of action. The magma is usually more or less thoroughly injected into the encasing rocks along their structural planes or across the beds in fracture fissures. The encasing rocks are usually shattered and angular fragments are scattered out into the body of the irruptive. There is usually abundant evidence of more or less dynamic metamorphism independent of the contact metamorphism. These phenomena are lacking in connection with the Weary Flat batholith. The rocks of the district are folded, to be sure, but they appear to have been thus folded anterior to the batholithic invasion, and the flexures are, besides, quite open. We must thus conclude that the intrusive act was of a rather mild type and that the pressures within the magma, which gave rise to the invasion from below, were not far above the point of equilibrium when it had reached this stage in its upward path through the earth's crust. Perhaps this is only another way of saying that we have here to deal with the summit of a batholith, the level in the liquid column where its intrusive force was about spent; and that at deeper levels, had they been exposed by erosion, we should have had revealed to us the more commonly observed phases of intrusive phenomena.

If we adopt this suggestion we have in it an explanation of the peculiar geomorphy of Weary Flat. This is a very even slope everywhere underlain by the monzonite. It lies at the headwaters of a very feeble desert stream, with no catchment area behind it, so that we can not interpret the flat slope as due to stream planation. It is more probable that the present surface of the monzonite is nearly coincident with its original upper limit where it was overlain by the soft White Pine shale. In this view of the case the geomorphic expression is strictly controlled by structure and the structural feature involved is the nearly flat contact plane between a batholith of hard rock and the roof of an overlying soft rock.* If it were otherwise, then the Weary Flat slope must be due to the planation of the monzonite; but this is highly improbable, since there are no residual knobs of the latter, and the soft shale occupies higher ground on three sides of the mass. It may, therefore, be safely assumed that the batholith was nearly flat topped, and that this flat top is practically the present surface as revealed by the denudation of the shale roof.

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* Cf. The Geology of the Upper Kern Basin, Bull. Dept. Geol. Univ. Cal., Vol. 3, No. 15, pp. 312 *et seq.*

Age of the Monzonite.—The only rocks actually penetrated by the monzonite are the Nevada limestone and the White Pine shale of the Devonian. At one point only, a little to the south of Pilot Knob, does the monzonite, cutting across the entire thickness of the White Pine shale, reach the contact plane between this formation and the overlying Ely limestone. It does not appear to rise above this stratigraphic horizon. The evidence is thus positive as to its post-Devonian age. The recognition of the flat topped character of the monzonite bathoilth precludes us from assuming that it ever penetrated higher into the Carboniferous formations where they are now removed by erosion. Yet it requires but little reflection to make it clear that the date of the intrusion is not only post-Devonian but also post-Carboniferous. The investigations of the geologists of the 40th parallel survey and those of Hague at Eureka and White Pine indicate that the Carboniferous and Devonian formations of this part of Nevada form a perfectly conformable sequence. This is confirmed by the writer's studies in the limited field of the Robinson Mining District. It seems to be quite inconsistent with this idea of conformity that so important a disturbance as the intrusion of a batholith could have affected the Devonian rocks in pre-Carboniferous time. The strata of both the Carboniferous and the Devonian are deformed to the same extent and seem to have suffered this deformation anterior to the invasion of the monzonite into the Devonian. If we should assume that the Carboniferous and Devonian are not in reality conformable, but only apparently so, then, since the monzonite cuts across the entire thickness of the Devonian, its upper surface must be due to erosion, and we should expect a conglomerate or an arkose at the base of the Carboniferous. But no such formation exists here at the base of the Carboniferous. Moreover, since the monzonite cuts across the entire thickness of the Devonian, if it were intrusive in the Devonian prior to the deposition of the Carboniferous and were not exposed by erosion, it must have appeared at the surface and would partake of the characters of a volcanic extravasation. But it has none of these characters and is thoroughly plutonic in its habit. We are, therefore, constrained to regard the time of the intrusion as post-Carboniferous.

Contact Phenomena.—Along the contact of the monzonite with the Nevada limestone and with the White Pine Shale, it has been mentioned that considerable bodies of garnet rock occur as a product of contact metamorphism. These are not without interest from an economic point of view since at their outcrops they afford indications of the presence of copper ores. These indications are usually in the form of malachite and azurite stains and deposits in more or less decomposed and rusty rock. Several prospect pits and tunnels have been cut into this contact zone and have in several cases resulted in finding chalcopyrite interlaminated or interspersed through the garnet mass. As yet, however, no important deposits of ore have been found in this situation, the most favorable being at the Taylor claim, near the apophysis of the monzonite already mentioned to the north-northwest of Pilot Knob, a little beyond the limits of the map. Here very good ore is found in the garnet rock, but the question as to its quantity had not been settled at the time of the writer's visit in 1904.

The Nevada limestone on the contact of which the garnet rock is most abundantly developed is, in several cases observed, thoroughly marmorized. A typical sample of the garnet rock from a pit to the north of Pilot Knob was examined microscopically. It consists of a mesostasis of garnet partly isotropic and partly doubly refracting. In this are imbedded rather numerous irregularly bounded, but more or less elongated, colorless crystals with a high refractive index and a strong double refraction. These crystals have a cleavage parallel to the elongation and the angles of extinction measured against this cleavage have a high value. It is very probable, therefore, that the mineral is diopside. With the diopside there are also numerous stout hexagonal prisms of apatite. There are also areas of calcite, of quite irregular boundaries, and areas of limonite in the garnet. The rock effervesces freely with dilute acid.

Another sample of garnet-chalcopyrite ore from the shaft on the Taylor claim consists mostly of garnet with rough jagged fracture shot through with chalcopyrite. The rock has a rudely sheeted structure. In thin section the field is murky and consists of nothing but impure doubly refracting garnet, more or less distinctly idiomorphic, with interstitial chalcopyrite carrying small irregular grains of quartz.

Petrographical Character.—The normal facies of this intrusive mass is a medium textured gray rock composed of whitish feldspar and black hornblende as a matrix in which are imbedded large flesh tinted fresh feldspars up to 15 mm. in size. A very sparing amount of quartz may be detected with a lens on weathered surfaces. The feldspar was assumed in the field to be orthoclase and the rock was designated a syenite. A microscopic study of the rock, however, shows that there is a large proportion of plagioclase giving extinction angles in sections normal to (010) up to 20°, and having a refractive power greater than that of balsam. This feldspar, having the characters of andesine, is not less in amount than the orthoclase, a fact which clearly indicates that the rock should be classed with the monzonites rather than with the syenites. The orthoclase is distinguished in general from the andesine by the absence of twinning and by the fact that it shows a lower refractive power than the balsam. The hornblende occurs in fairly idiomorphic crystals of small size. Quartz is very sparingly represented in the section. The accessory minerals are apatite, titanite, and magnetite. The structure is hypidiomorphic granular as regards the general body of the rock; but this serves as a matrix for large phenocrysts of orthoclase. The phase of this monzonite cutting the limestone and shale at the Taylor Mine to the west of Pilot Knob shows some minor variations from the prevailing character of the mass underlying Weary Flat. In the specimens taken from this locality the ground mass is finer grained and the phenocrysts are more numerous. The hornblende, where fresh, occurs in longer prisms, but much of it is represented only by pseudomorphs of limonite. Quartz is a little more abundant. Apatite and titanite are more prominently developed. The large phenocrysts of orthoclase attain a length of 25 mm. and they often show Carlsbad twinning. A contact facies of the monzonite where it comes in contact with the Nevada Limestone on the roadside just north of the Monarch Claim was studied in specimens taken from a prospect pit on the contact. The rock is a medium grained, gray, porphyritic rock made up apparently chiefly of feldspar with a subordinate admixture of a dark mineral. In thin section the rock appears as an allotriomorphic aggregate of orthoclase and plagioclase in which are imbedded numerous phenocrysts of light green augite and a few green hornblendes. The accessory minerals are apatite, titanite, and zircon in rather numerous but small crystals and a few granules of iron ore. Another specimen from the same pit is finer grained and more decomposed. It effervesces feebly with dilute acid. In thin section the rock is an aggregate of more or less idiomorphic feldspars now wholly replaced by calcite and kaolin and some yellow epidote. Nearly colorless chlorite occurs in nests, representing, doubtless, the decomposition product of an original ferromagnesian constituent. Large crystals of apatite are notable features of the slides, and considerable titanite is present. A very little secondary quartz may also be detected.

Chemical Composition.**—The identification of the rock as a** monzonite on the basis of microscopic study is confirmed by a chemical analysis which has been made by Mr. Herbert Ross since the above was written. The sample selected for analysis was taken from a prospect pit on Weary Flat to the south of the road between Copper Flat and Pilot Knob. The analysis of the rock from Hodritsch, Hungary, quoted from von Hauer by Brögger* as that of a typical monzonite is cited for comparison. The two analyses are given in the following table:

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* Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo in Sudtyrol, p. 50.

ANALYSIS OF MONZONITE.

	Weary Flat, Nevada.	Hodritsch, Hungary.
SiO_2	61.69	61.73
Al_2O_3	17.26	17.45
Fe_2O_3	3.53	5.94
FeO	1.91	....
MnO	.09	....
MgO	1.45	2.29
CaO	5.49	4.52
Na_2O	3.05	3.12
K_2O	3.88	3.88
BaO	.10	....
P_2O_5	.34	....
Cl	.03	....
H_2O (ig)	.73	1.16
	99.55	100.09

The mineralogical composition of the rock as inferred from the analysis may be expressed approximately as follows:

	Per cent.
Orthoclase	23.00
Albite	26.00
Anorthite	22.00
Hornblende	15.00
Quartz	13.00
Apatite	.65
	99.65

It would appear from this that a very large proportion, if not all, of the orthoclase is present in the form of the large phenocrysts, the matrix of the rock in which these are imbedded having the character, when considered by itself, of a quartz diorite which consolidated at the eutectic point of the cooling magma. The amount of quartz revealed by the analysis is somewhat higher than was inferred from the microscopic study of the rock. The presence of small quantities of manganese and barium is noteworthy. In spite of the fact that copper ores occur at the contact of this monzonite with the encasing formations, neither the results of the analysis nor the fresh condition of the rock lend support to the idea that such copper was derived from the monzonite. The absence of sulphides is a noteworthy feature of the rock, and is a point of striking contrast with other igneous rocks, to be described later, which have an important relation to copper ore bodies. It is to be remarked, however, that rocks of the monzonite class are being more and more recognized in regions where copper ore abounds. Possibly the rock contains traces of copper which cannot be detected by the ordinary methods of analysis, and this may be brought up from the deeper portions of the irruptive mass, whence come the aqueous emanations that induce the formation of garnet and other contact metamorphic minerals, including chalcopyrite.

MONZONITE PORPHYRY DYKES.

At several localities within the district, but most abundantly on the border of the area mapped on the north side of Lane Valley, there occur dykes of a remarkably coarse porphyritic rock, a petrographical study of which reveals its character as a monzonite porphyry. To the north of Lane City the dykes are of large dimensions and at their contact with the limestone there is commonly developed an abundance of garnet rock. Specimens taken here may be described as having a greenish gray ground mass in which are imbedded huge crystals of fresh orthoclase with flesh tinted, lustrous cleavages, smaller feldspathic phenocrysts and black hornblendes.

Petrography.—Under the microscope the ground mass appears as a microgranitic aggregate of non-striated feldspar and quartz, the former predominating. In this ground mass are imbedded idiomorphic phenocrysts of orthoclase, plagioclase, green hornblende, green augite, abundant titanite, a few large apatites, and an occasional much corroded crystal of quartz. The plagioclase has the optical characters of oligoclase. It is, however, commonly zoned. Combinations of Carlsbad and albite twinning are of frequent occurrence. The hornblende is strongly absorbent. The augite is of a clear chrome-green color, nonpleochroic, octagonal in sections transverse to the prism, and exhibits a strongly marked cleavage, against which the extinction in longitudinal sections reaches 40°. The titanite is a remarkable feature of the slides, some large crystals showing fine twinning. The apatite is in part inclosed in the hornblende. There are also a few grains of opaque iron ore. The smaller feldspars range up to about 4 mm. in their longest dimension, and the hornblendes attain a length of 6 mm., while the large orthoclases are usually from 10 to 20 mm. in length, though in some phases of the rock they are as much as 50 to 75 mm. long and proportionately broad. In other specimens of the rock from the same locality no quartz can be detected with certainty, and the orthoclase and plagioclase, the latter having a maximum extinction angle in the zone normal to (010) of 23°, occur in about equal proportions.

In the vicinity of the copper bearing porphyry four occurrences of this monzonite porphyry have been found, all of them quite limited in extent. Of these, two are found in the Ruth limestone, one in the Arcturus limestone, and one in the porphyry itself, but so near its contact with underlying limestone that it is quite doubtful whether it really cuts the porphyry or not. They all have the same general microscopic characters and, although their actual contact with the surrounding rock is in no case exposed, they can only be interpreted as dykes. In the northwest corner of the Spion Kop claim the monzonite porphyry dyke presents a greenish gray matrix in which are imbedded flesh tinted orthoclases with Carlsbad twinning, an occasional crystal of yellow titanite, nests of epidote and some scattered cubes of pyrite. In thin section the rock is seen to be much decomposed. The ground mass is a holocrystalline, panidiomorphic aggregate, consisting chiefly of feldspar in which secondary calcite, epidote and pyrite occur very commonly. In this are imbedded the large orthoclases, titanite, a little quartz and a ferromagnesian mineral changed almost wholly to chlorite. No lamellar twinning was observed in the feldspars, but it is probably obscured by the decomposition which has affected them.

A similar dyke is exposed in a small prospect hole near the forks of the road to the west of the Ruth Mine. The rock is the same as that just described except that apatite is a notable feature of the slides.

Another occurrence is in the saddle of the ridge just north of the Blair claim. The rock here has a compact gray matrix in which are imbedded large orthoclase crystals up to 25 mm. in length with Carlsbad twinning and fresh lustrous cleavages, smaller, dull white feldspars and numerous black hornblendes up to 15 mm. in length. Under the microscope the ground mass proves to be very murky. It is largely isotropic but with doubly refracting areas in it. The smaller feldspars can not be advantageously studied owing to their decomposition. Apatite is a common accessory.

The fourth occurrence is about a quarter of a mile to the southeast of the Ruth Mine. Macroscopically it resembles the occurrence on the Spion Kop claim and under the microscope it differs from that rock only in the presence of apatite in the thin slides.

Chemical Composition.—A representative specimen of the monzonite porphyry taken from the occurrence north of Lane City was analyzed by Mr. Ross with the following results:

SiO_2	59.79
Al_2O_3	17.70
Fe_2O_3	2.42
FeO	2.76
MgO	1.92
CaO	5.22
Na_2O	2.64
K_2O	4.19
BaO	.21
MnO	.09
P_2O_5	.37
H_2O (ig)	2.00
	99.31

Relation to Monzonite Batholith.—The analysis is noteworthy for its close similarity to that of the monzonite of Weary Flat. This similarity of chemical composition suggests an identity of magma for the two rocks. So far as the field evidence is concerned there is little that can be adduced in opposition to this suggestion. The monzonite porphyry may be the dyke facies of the monzonite of Weary Flat. The one doubt that arises is due to the occurrence of a very small mass of the monzonite porphyry within the area of the copper-bearing porphyry near the north boundary of the Blair claim. This, however, is so near the contact of the porphyry with the underlying limestone that it may be interpreted as a portion of the floor upon which the porphyry rests, that is, as a dyke cutting the limestone but not the porphyry. If the monzonite porphyry is thus to be regarded as directly and genetically connected with the monzonite of Weary Flat as a dyke facies, it is remarkable that the phenocrysts of the small intrusive masses (dykes) are as a rule many times larger than the crystals of the same mineral in the larger batholithic mass of which the dykes are apophyses. In support of the correlation of these dykes with the Weary Flat monzonite, the further fact may be mentioned that the contact phenomena of both rocks against the limestones is closely the same, particularly in the development of large bodies of garnet rock. On the other hand it is somewhat remarkable that none of these dykes have been observed anywhere on the immediate periphery, or, indeed, in the vicinity, of the main mass of monzonite at Weary Flat. In view of the absence of direct evidence of connection between the two rocks, it must be confessed that the question of their relationship remains as yet unsettled, but the view that the dykes are apophyses of the batholith seems fairly probable.

THE COPPER-BEARING PORPHYRY.

The term porphyry is here used in the popular sense. In mining communities the term is applied very freely to the lighter colored volcanic and intrusive rocks in much the same way that the expression trap is used for the darker rocks of basaltic character. It is very rarely applied to rocks of plutonic habit. It is particularly used for intrusive and volcanic rocks with which ores are directly or indirectly associated. The usage is not definitive and affords little or no intimation as to the place of the rock so named in any system of classification. To the petrographer the term is simply descriptive of the presence of a porphyritic structure which is common to many different kinds of rocks; but in the popular usage even this is not essential

In the present case the popular term is the more readily adopted as a preliminary designation from the fact that owing to its very thorough decomposition the rock we are here concerned with is difficult to classify. It is a light yellowish or whitish feldspathic rock with a prevalent porphyritic structure and a general absence of ferromagnesian minerals. Its more precise characterization and its variations will appear from the detailed descriptions to be given after its broader features as a factor in the geology of this field have been considered.

Extent.—An inspection of the geological map of the district will show that the porphyry occupies two quite distinct areas. One of these extends from Copper Flat westward to Rusty Ridge at the west of the map. This area has an east and west extent of nearly three miles and a maximum width of five-sixths of a mile. The area is continuous and there are no outlying patches of the same rock in its vicinity.

The second area extends from Ocher Valley eastward to a little beyond the eastern limit of the map near the Chainman Mine. This area has also an east and west extent of about three miles and a maximum width at the Ruth Mine of about three-fifths of a mile. This area is more irregular in outline and less continuous than the western area. It has in fact, in consequence of its dissection by erosion, been separated into two distinct parts, the less extensive of which is in the vicinity of the Saxton and Chainman Mines. These two areas of porphyry lie in a distinct east and west allignment and form a belt of rock traversing the district which has determined not only the distribution of the economically important minerals but also the evolution, under erosion, of the geomorphic features of the region. It is noteworthy that this allignment and the features determined by it are transverse to the general trend of the Egan Range and to its dominant structural lines.

The break in the continuity of the porphyry belt at Ocher Valley in the central part of the district might on a rapid survey be referred to its dissection by erosion, but a more careful examination of the contact between the porphyry and the adjacent rock shows that there is little warrant for this view, and that the two areas probably have always been distinct at the surface, although doubtless connected at depth.

Intrusive Relations.—The evidence as to the relations between the porphyry and the adjacent Palaeozoic formations is in general quite satisfactory and establishes the fact that the porphyry is intrusive in the sedimentary rocks. This evidence is of two kinds: (1) the structural relations of the porphyry mass to the surrounding strata; and (2) the contact metamorphism displayed at several points on the margin of the porphyry.

Structure.—The structural evidence of the intrusion of the porphyry is perhaps most apparent in the eastern area and particularly in the vicinity of the Ruth Mine. Here the porphyry belt lies transverse to a well marked northerly pitching syncline of the Ruth limestone. On the south side of the porphyry belt different stratigraphic horizons of the Ruth limestone abut upon it and the plane of contact does not conform to the planes of stratification, but in general appears to dip under the porphyry. On the north side of the belt, the Ruth limestones overlie the porphyry, dipping away from it but again meeting it at different stratigraphic horizons. It is evident from this relationship not only that the porphyry is intrusive in the Ruth limestone, but, also, that the intrusion occurred subsequent to the establishment of the synclinal structure.

The way in which the upper surface of the porphyry passes beneath the limestone at low angles on the north side of the belt, the strata dipping away from the intrusive mass, suggests strongly that the structure is, in general, for this part of the belt, laccolithic. On both flanks of the Ruth syncline the porphyry comes in contact with the underlying Arcturus shaly limestone. On the west flank it appears to pass beneath the Arcturus formation although cutting across various horizons. On the east it passes over upon the Arcturus formation.

On Jupiter Ridge and from thence eastward to the Chainman Mine, the mapping of the porphyry indicates that it lies upon the White Pine shale as a warped sheet, partly removed by erosion, but cutting across the contact of the shales with the overlying Ely limestone. On the lower flanks of this slope at the upper end of Lane Valley, it is mantled by the remnants of a roof of limestone and it probably sustains a similar relation to two other areas of limestone between this and the Chainman Mine although this relationship was not established in the field.

In the western area of porphyry the laccolithic character of the intrusion is even more apparent. Along the eastern edge of this area, in the vicinity of Copper Flat, the upper surface of the porphyry passes beneath the western edge of the Arcturus shaly limestone at a rather low angle. To the west of Copper Flat, however, beyond the northeast-southwest fault shown upon the map, the base of the porphyry mass may be traced without a break for about two miles and a half, resting first upon the White Pine shales, then upon the Weary Flat monzonite, then upon the Ely limestone, then upon the shales again and finally upon the Ely limestone to the north of Rusty Ridge. West of Weary Flat, the trend of this lower edge of the porphyry mass is transverse to both the strike and dip of the strata upon which it rests; and it is evident from the mapping that the rupture, through which the porphyry magma welled up from below, was formed, as in the case of the mass lying in the Ruth syncline quite independently of the preëxisting structure as expressed in stratification and flexure.

On the south side of this western area of porphyry, the upper surface of the intrusive mass cuts across the strata of the Ely limestone in the Rib Hill anticline and appears to pass beneath it. On the western flanks of this anticline it cuts similarly across the strata of the Arcturus formation while plunging beneath it. At the extreme western limits of the porphyry belt the intrusive mass seems to wedge out rather abruptly but this point did not receive as much attention as the writer would like to have given it.

From the above summary statement of the structural relations of the porphyry to the rocks which are adjacent to it, there can be left no room for doubt as to its intrusive character. The suggestion that the intrusion is of the nature of a laccolith may, perhaps, be questioned on the ground that the mass cuts across the strata of the encasing formations. That it does so is probably due to the fact that the strata were folded anterior to the intrusion. The laccolithic chamber for the reception of the magma, particularly in the western area, has a floor, which while uneven, appears to have an approximation to the horizontal, and the impression that one gets from the mapping is that the horizontal dimensions of the mass are much greater than the vertical. There seems to be little question but that the sedimentary rocks once arched completely over all of the porphyry, although there may of course have been vents in the arch to the surface as it existed at the time of the intrusion.

Contact Metamorphism.—The conclusion which has been reached on purely structural grounds as to the intrusive character of the porphyry is confirmed by evidence of contact action which has been detected at various points on the periphery of the mass. The southern border of the porphyry to the east of the Ruth Mine is characterized by a zone of vermilion colored earthy material which lies between it and the limestone. To the south of the porphyry, immediately opposite the Ruth Mine, the first rock that one meets is passing from the intrusive toward the Ruth limestone is a body of yellowish green garnet rock associated with magnetic and limonitic iron ore.

The garnet rock has frequently a miarolitic structure, showing cavities with drusy crystals of garnet up to 2 mm. in diameter. Occasionally there is a green copper stain. Even the most massive phases of the rock appear in thin section to be made up of an aggregate of fairly well formed crystals. The garnets are isotropic. There are occasional small veins of quartz traversing the garnet, and small areas of yellow stained quartz aggregates occur. The iron ore with which this garnet rock occurs is found in considerable bodies over several acres of ground but is not intermixed with the garnet. In hand specimens it is feebly magnetic, shows yellowish stains and has the yellow streak of limonite. In thin section it is chiefly opaque, but is shot through with irregular areas and veinules which are translucent to reddish yellow light. The ore is evidently a mixture of limonite and magnetite. A sample analyzed by Mr. Ross contained 65.6 per cent. iron.

At the contact of the porphyry with the Ely limestone on the Jupiter claim, there have been developed bodies of yellowish green garnet rock which, in thin section, is seen to be an aggregate of more or less idiomorphic crystals of doubly refracting garnet, with angular spaces between the crystals filled with calcite.

At the same contact on the Emma G. claim, the limestone has been changed to a white marble or a mixture of calcite and garnet. In places it may be called a garnet rock with a subordinate proportion of calcite, in which are imbedded irregular grains and idiomorphic crystals of quartz. Associated with the calcite is a biaxial mineral with lamellar structure, a refractive index less than that of quartz, a double refraction about that of quartz or less, a pronounced cleavage and a twin structure, which is thus identified as gypsum. Where the garnets prevail the structure is miarolitic; where the calcite prevails the garnets occur in nests and stringers through it.

At another locality on the same contact a yellowish garnet rock occurs with drusy surfaces, in cracks, of small yellow garnets and small veins of calcite. The garnet in this case has a zonal structure and is doubly refracting. Nearly colorless epidote occurs in aggregates of grains enclosed in the garnet.

Just to the west of Copper Flat and at Pilot Knob occur considerable bodies of iron ore which seem to have the same relation to the porphyry that the iron ore at the Ruth does, although the porphyry, particularly at Pilot Knob, has been well removed by erosion from the immediate vicinity of the ore. The iron ore at Pilot Knob is a black to metallic gray magnetite with a somewhat vitreous luster. It is compact and shows no granular structure. Thin sections are quite opaque except for a few areas and veins translucent to reddish yellow light. This is the largest body of iron ore observed in the district.

It is noteworthy that all the observed occurrences of this contact garnet rock and iron ore are on the lower side of the porphyry mass. It is also to be remarked that, while these products are regarded as the result of contact metamorphism, they can in no sense be ascribed simply to thermal metamorphism in the same way that common limestone is converted into marble, or a clay state to an andalusite hornfels* without change of bulk composition. It is evident that they are the products of a reaction between the intrusive porphyry and the adjacent limestone. The lime of the garnets was doubtless derived from the limestone, but the carbonic acid was eliminated and the silica must have been derived from the porphyry. The most probable means whereby the reaction was effected was aqueous solutions emanating from the porphyry and, this being the case, the process of garnet formation might have gone on, and probably did go on, after the actual solidification of the intrusive mass.

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* *e.g.*, The contact zone at Barr Andlau described by Rosenbusch.

Regarding the origin of the iron ore little can with confidence be stated. This much is known, however, that bodies of iron ore similar to those occurring in this district, and often on a much larger scale, are common at the contact of intrusive rocks with limestone. In some cases these ore bodies are known to have originated long after the solidification of the igneous rock and to have resulted from the leaching of the iron from it and its precipitation at the contact with the limestone. It would, therefore, again not seem necessary to regard the iron ore as in any way the product of the direct reaction of the molten magma upon the limestone, but an after product, due to the precipitation of the iron oxide at the contact of the limestone from soluble salts due to the downward leaching of the porphyry. The particular reaction which has effected the precipitation of iron oxide by carbonate of lime under such circumstances is not known, but doubtless a chemical investigation would make it clear.

At the contact of the porphyry with the monzonite of Weary Flat the former is curiously modified locally. In some prospect pits that have been opened along the wagon road between Copper Flat and Pilot Knob, the monzonite is exposed in proximity to the overlying porphyry. Here, the only part of the monzonite that is left is the large porphyritic crystals of orthoclase, and even these are charged with limonite giving them a yellow color. The form and cleavage of the orthoclases are intact and the faces reflect the light well. All the rest of the rock, or the entire matrix in which the porphyritic orthoclases are imbedded, has been altered to a reddish cellular aggregate of limonite and silica. In thin sections of this altered rock the orthoclase is perfectly fresh, showing no kaolinization products, although containing much limonitic pigment. Carlsbad twinning is common, and in some sections free from limonite a good biaxial figure was obtained. The index of refraction is less than that of balsam. The matrix in which these large orthoclases are imbedded appears under the microscope to be composed of nothing but limonite and secondary quartz in rather large grains and aggregates of such grains. There are some dusty inclusions in the quartz, but no liquid inclusions could be detected.

The modification of the monzonite just described is clearly a contact phenomenon, but it can not be ascribed to the direct influence of the porphyry magma upon the underlying rock. It is with little doubt due rather to a subsequent action in which the chief reagents concerned were derived from the porphyry by a process of downward leaching, though why all the feldspars of the main body of the rock should have been destroyed and only the porphyritic orthoclases left intact, remains a mystery.

Petrographical Characters.—The porphyry in general has suffered so much alteration since its solidification that it has proved difficult to find material upon which to make a study of the rock in its original condition. At a few localities, however, specimens were obtained which being less decomposed than the rest of the mass have contributed some information on this point. They are not, however, uniform in character and doubt still remains as to the prevailing petrographical features of the rock prior to its alteration. Some of these will now be briefly described.

At the head of Lane Valley, on the south side, a tunnel has been run into a mass of the porphyry where it emerges from beneath a limestone capping. Here the porphyry has a bluish, light gray color and may be seen in hand specimens to consist of a dense matrix in which are imbedded numerous small phenocrysts of dull feldspar up to 3 mm. in length and fewer large phenocrysts of another feldspar of fresh glassy appearance up to 12×6 mm. in size. The rock is shot through with pyrite mostly in disseminated grains but also in nests and small veins. The rock effervesces freely in acid.

In thin section the ground mass is a micrographic aggregate of untwinned feldspar with a subordinate amount of quartz and a great deal of secondary calcite. In this are imbedded idiomorphic feldspars of small dimensions thoroughly altered to an aggregate of decomposition products and also much larger phenocrysts of fresh orthoclase containing shreds of calcite, some phenocrysts of bleached biotite and grains of pyrite with blurred outlines. None of the pyrite is enclosed in the feldspar phenocrysts. The feldspar of the ground mass has a distinctly lower refractive index than the balsam and this taken with its non-twinned character indicates that it is orthoclase.

Across the road from the last locality, a few hundred feet distant, a shaft has been sunk into the porphyry at the base of a vertical limestone bluff. Here the rock is of a light gray color and strongly porphyritic. A blue-gray dense matrix holds abundant dull white phenocrysts of feldspar ranging up to 4 mm. in length, besides occasional much larger phenocrysts of orthoclase in Carlsbad twins up to 15 mm. in length. Throughout the rock is disseminated much pyrite which is locally bunched in nests and veins, and in portions of it there are large crystals of fluorite the cleavage faces of which range up to 25 or 30 mm. in breadth. The pyrite does not occur in the phenocrysts but occurs freely in the fluorspar. The rock effervesces with acid.

In thin section this rock shows remnants of a holocrystalline feldspathic ground mass, much replaced by calcite, with grains of quartz scattered through it. In this are cloudy feldspar phenocrysts wholly altered, shreds of white mica of considerable size and small scattered grains of pyrite. The larger phenocrysts of orthoclase are fresh and show Carlsbad twinning. The white mica is probably a bleached biotite. Some portions of the rock are so charged with sulphides as to constitute ore. A specimen of such ore shows numerous parallel and obliquely intersecting seams of chalcocite and pyrite alternating with thin sheets of rock more thoroughly kaolinized than the rest. The seams vary from 1 to 2 mm. in thickness. A little gypsum is plastered on the surface of the specimen.

At the first fork of the road east of the Ruth Mine, the rock has a bleached white appearance with occasional yellow iron stains. The porphyritic structure is very pronounced. The phenocrysts are of two kinds: (1) Remains of sharply idiomorphic feldspars of a dull white color and ranging usually from 2 to 5 mm. in length, though sometimes attaining 10 mm. (2) Lustrous white blades—evidently pseudomorphs of some ferromagnesian mineral from which the iron has been leached. These phenocrysts are imbedded in a matrix which under the lens appears to consist almost altogether of silvery white scales lying in a felt work. This felted matrix is quite open and porous in texture. Under the microscope the white scaly mineral of the matrix has the properties of kaolin and has some quartz associated with it. The feldspar phenocrysts are represented by an aggregate of white mica scales and quartz. The broad blades prove to be white mica probably a bleached biotite. One crystal of zircon was detected and a few minute crystals of brown hornblende.

On the hill to the west of Copper Flat shaft house the porphyry is yellowish in appearance and with the lens is seen to be of a porous or honeycomb texture. Quartz veins 5 or 6 mm. thick traverse it, also small zones of secondary quartz without definite walls. The porphyritic structure is quite apparent, but the feldspars are of a dull earthy appearance, as is, indeed, also the matrix in which they lie. There is no effervescence with acids.

In thin section much of the field is turbid with yellow stained scarcely translucent decomposition products. Between patches of this kind is an aggregate of untwinned feldspar and quartz. Cavities are numerous. Pseudomorphs of sharply idiomorphic feldspars, in a very turbid condition, are numerous.

On the south side of same hill as that on which the last specimen was taken, the porphyry is a dull white rock with drusy cavities and irregular patches of blue gray quartz. There are very faint traces of a porphyritic structure. In thin section the ground mass consists of untwinned feldspar and some quartz in which are occasional phenocrysts of orthoclase with Carlsbad twinning and numerous larger grains and areas of secondary quartz. A brownish isotropic decomposition product occurs in patches through the slide and there are besides these stains of limonite.

At the Copper Flat Mine the porphyry when charged with sulphides becomes a copper ore. A sample of the ore from the dump of the mine is a dull white rock showing occasional cleavages of feldspar phenocrysts which is traversed to the extent of half its volume with light colored quartz stringers ramifying in all directions. Both the dull white rock and the quartz have chalcocite and pyrite disseminated through them. The pyrite also occurs in nests and veinlets.

A thin section shows only quartz in allotriomorphic granular aggregate with numerous irregular grains of opaque sulphides. In the quartz are abundant liquid inclusions with bubbles and numerous small ragged nearly opaque solid inclusions are scattered through it.

Another sample of the porphyry taken from near the bottom of shaft No. 2, of the same mine, is a light gray rock with vague and uncertain traces of porphyritic structure. Rather large stringers of quartz, large nests of bronzy mica and stringers and disseminated grains of chalcocite and pyrite are common in the rock.

In thin section the rock is seen to be an allotriomorphic granular aggregate of quartz and biotite, with a small shear zone running through it. The biotite is evidently secondary with the quartz and the sulphides.

A specimen of the porphyry from the Josephine claim exhibits a characteristic phase resulting from extreme silicification. Microscopically it is a mass of honeycombed quartz with patches of light yellow ochre. Under the microscope the rock is composed only of quartz in an aggregate of fairly uniform sized anhedrons, with patches of yellow ochre.

Chemical Composition.—It is evident that a rock varying so much in degree of alteration as the porphyry is difficult to characterize chemically. Scarcely any two of the specimens described above as representative facies of the formation would yield the same results on analysis; and the results in every case would differ greatly from the original unaltered rock. The best that can be done in such a case, where the chief object is to determine the character of the fresh rock, is to select the least altered material available and subject it to analysis in the hope that, thereby, some light may be thrown upon the nature of the alterations which have affected it. This has been done. A sample of the rock from a tunnel at the upper end of Lane Valley, on the south side, was analyzed by Mr. Herbert Ross with the following results:

ANALYSIS OF ORE-BEARING PORPHYRY.

SiO_2	58.31
Al_2O_3	16.69
Fe_2O_3	....
FeO	....
MnO	.19
MgO	1.27
CaO	5.29
Na_2O	.20
K_2O	6.11
BaO	.35
P_2O_5	.31
Fe	2.27
S	2.79
Cl	trace
CO_2	3.47
H_2O	2.42
	99.67

Approximately this corresponds to the following mineralogical composition:

	Per cent.
Orthoclase	37.
Albite	1.5
Anorthite	2.
Biotite (residues)	3.5
Apatite	.6
Kaolin	22.
Pyrite	5.
Quartz	20.
Calcite	8.
	99.6

The analysis agrees with and confirms the description of the rock based on microscopic study (page 318) which was written before the analysis was made. It seems quite certain from the data thus obtained that the original rock was, as it still is, rich in orthoclase and that this mineral, part of the quartz and the apatite are the only constituents which have escaped alteration. It is clear from the analysis that water, sulphur and carbonic acid have been introduced into the rock from outside sources. Since the kaolin is probably chiefly derived from the breaking down of feldspars, it would seem probable that originally there was a notable proportion of plagioclase, the soda of which has been leached out and the lime of which has been converted into calcite. The surplus silica of such plagioclase over and above that fixed in the kaolin has probably also been removed. The pyrite has doubtless resulted from the reaction of sulphur bearing solutions upon the iron of the biotite which is now bleached white, thus accounting for the absence of oxides of iron in the analysis of the rock.

In view of this interpretation it seems pretty certain that structure of this facies of the rock is much better preserved the original rock had the characters of a rhyolite. The original than its mineralogical character and seems to have been holocrystalline. This, however, may be due to its rather deep seated situation and more superficial portions may quite possibly have been hypocrystalline.

Resumé.—Reviewing now the petrographical descriptions of the porphyry from various localities, it would appear that we have a gradation in the degree of alteration to which the mass as a whole has been subjected, ranging from that exemplified in the specimen analyzed to cases where every trace of the original minerals has been removed and nothing has been left but an aggregate of cellular secondary quartz constituting a phase of the quartz blout. This extreme end product is, however, probably quite superficial since in all underground openings in the porphyry there is an abundance of kaolin in the rock with notable quantities of residual feldspars. It probably represents a result of the weathering of the kaolinized and silicified mass as it became exposed to the direct attack and downward leaching of meteoric waters above the ground water level. Setting aside this extreme facies of the altered porphyry as a superficial phenomenon, we may safely characterize the porphyry in general as a very much kaolinized, silicified, carbonated and pyritized rhyolite.

Porphyry at the Chainman Mine.—Near the Chainman Mine mill there is exposed, in a road cutting, a mass of porphyry which is quite different in its general physical characters from the main body of the copper-bearing porphyry above described. It is very probably, though not certainly, a distinct intrusion from the general body of the porphyry. It is, however, mapped with the latter. The rock is quite fresh and shows little or none of the tendency to kaolinization and silicification to which the common facies of the porphyry seems so prone. In hand specimens it is a compact, light yellowish gray rock, showing numerous small porphyritic feldspars of a fresh glassy aspect.

Under the microscope this is seen to consist of a fine holocrystalline ground mass made up of allotriomorphic and interlocking feldspars, some of which show lamellar twinning. These are approximately equidimensional and generally free from decomposition products. In this ground mass are imbedded numerous phenocrysts of plagioclase, colorless augite, and apatite. The feldspar in sections normal to (010), showing both Carlsbad and albite twinning, have extinctions corresponding to the composition Ab_2 An_3.

The rock thus appears to be a pilotaxitic augite andesite. The fresh condition in which this rock occurs promised satisfactory results on analysis. A selected sample was, therefore, placed in the hands of Mr. Herbert Ross of the Ruth Mine, who kindly made a chemical analysis with the following results:

SiO_2	63.30
Al_2O_3	17.90
FeO	1.83
MgO	2.53
CaO	10.45
Na_2O	2.30
K_2O	....
P_2O_5	.69
H_2O CO_2 } ig	1.18
	100.18

QUARTZ BLOUT.

Term Defined.—Perhaps the most remarkable feature of the porphyry is the occurrence, in the areas occupied by the latter, or on their periphery, of large bodies of quartz of somewhat varying character. These bodies of quartz are by no means uncommon features of decomposed and mineralized eruptive rocks in Nevada and elsewhere; and the prospectors and miners, who have to deal with them practically, usually distinguish them from ordinary vein quartz by characterizing them as "blow outs.'' This discrimination appears to the writer to be well warranted. They cannot be regarded as veins or lodes; and while, as will be shown later, they are to a large extent replacements of other rocks, they may not be wholly so. They constitute a particular mode of occurrence of quartz which the writer desires to distinguish both from vein quartz and from replacements of country rock by silica in the vicinity of veins. To signalize the distinction and to simplify their discussion, the miners' term ''blow out'' will be adopted in the modified form of *blout,* and they will, therefore, be referred to henceforth as *quartz blout,* much in the same sense as one would use the expression ''quartz vein.'' Similarly as we designate the quartz of a vein specifically as ''vein quartz,'' so here we may refer to the quartz of which the blouts are composed as *blout quartz.*

Field Relations.—The most striking feature of these quartz blouts is their vast size as compared with ordinary veins. A glance at the map will show that in the vicinity of the Ruth mine they occupy a very considerable fraction of the area of the porphyry; perhaps one-third is occupied by the blout.

The mapping indicates that the greater part of the quartz blout lies on the periphery of the porphyry mass and occupies an intermediate position between it and the surrounding limestone; and although some important occurrences are more centrally situated, these from the mapping appear to be of the nature of caps upon the hill tops and ridges. If we accept the suggestion thrown out in an earlier portion of this paper, that the porphyry mass is of the nature of a laccolith, then these centrally situated quartz blouts are also peripheral, and represent a contact development between the porphyry and its roof of limestone now removed by erosion. Indeed, we can form a very consistent hypothesis to explain the distribution of the blouts by supposing that they were once a more or less continuous envelope, incasing the porphyry, particularly on its upper side, and intervening between it and the over arched roof of limestone. The removal of the limestone roof by erosion and the dissection of the envelope of quartz blout, leaving exceptionally thick or resistant portions of it as residuals reposing upon the porphyry, would well explain most of the occurrences. This hypothesis is borne out by the way in which the porphyry in the vicinity of the Ruth Mine passes at comparatively low angles beneath the Ruth limestone to the north, with considerable bodies of blout along the contact. On the west of the same porphyry mass the mapping of the blout is also very instructive, for there it is revealed as a sheet of considerable thickness flanking the porphyry, and extending from the summits of the hill down the slope to the floor of Ocher Valley, where it passes beneath the limestone. Mapping in other parts of the field shows the same general relations. We may thus assume with considerable confidence that the quartz blout is of the nature of an encasing shell developed, so far as the field evidence goes, chiefly upon the upper side of the porphyry laccoliths. It is, however, pretty clear also from the failure of the blout to appear at certain localities, where the contact of the porphyry and overlying limestone may be mapped narrowly, that this shell was not perfectly continuous. It is also very probable from a study of various occurrences, that the shell of blout was not only a partial one, but that it was of very variable thickness, and that the contact between the quartz and the porphyry was extremely irregular in detail, the quartz often penetrating down into the porphyry quite sharply. Some of this irregularity, however, may be explained by the excessive minor faulting, which as will be shown later, affects the porphyry throughout. Faulting must also be resorted to to explain certain subordinate occurrences of blout in depressions in the surface of the porphyry below the general level of the original shell, as for example, on the Josephine claim to the northeast of the Ruth Mine.

Besides these occurrences in immediate association with the porphyry, in the relations above indicated, there are others of minor importance as regards the scale on which they are developed, but which are nevertheless of much interest in throwing light upon the question of the genesis of the quartz blout. These occur not in the porphyry, nor on its contact with the limestone but wholly in the limestone. Some of these, while they are now quite disconnected from the porphyry, may have at one time been connected with it. The quartz blout of the Twin Peaks, for example, to the southeast of the Ruth Mine, may with much reason be regarded as representing a mass of peripheral blout about the porphyry in the vicinity of the edge or margin of the laccolith, which has since been caused to shrink in area by erosion, leaving the more resistant blout behind as a residual. If this view be accepted for such occurrences, they would need no special discussion as apart from the blout now found in the porphyry areas. There are, however, occurrences which can not be so explained. They lie wholly in the limestone and extend down into it as irregularly bulging and tapering masses which have some resemblances to veins but differ from these in the extremely abrupt and short lenticular habit which they affect.

Varieties of Quartz Blout.—The quartz of the blouts is by no means constant in character throughout the field. There are a great many varieties. These need not, however, be described in detail and it will suffice for purposes of description to class them under four subdivisions made on structural grounds. These are the (1) solid, compact quartz, (2) cavernous-weathering quartz, (3) brecciated quartz, and (4) cellular quartz. The first of these is the most common. It resembles closely a massive quartzite of granular but compact texture. Sometimes it is nearly pure quartz, glassy or whitish or but slightly yellowish in appearance, but for the most part it is deeply stained with iron oxide. The colors are sometimes disposed in a eutaxitic fashion, or it may be seamed with intersecting veinlets of more deeply colored jaspery quartz. It weathers in smooth, rounded knobs, or breaks down into a talus of irregularly angular blocks. Occasionally this variety shows a stratiform appearance but with no tendency to part along the planes between the different layers. The difference in the layers is usually due to both color and texture, flinty or cherty layers alternating with those of a more granular character. The cherty portions may be dark to almost black or may be light colored—yellowish or milky white. The granular portions, where not heavily stained by iron oxide, may be glassy or gray or very dark.

The cavernous variety of the blout quartz differs from the last described by its weathering out in extremely irregular forms with rugged chambers and straggling channels. In the bottom of the pits and chambers which characterize the weathered exposures of this phase of the blout quartz, remnants of limestone may be occasionally detected. In one case a mass of limestone about 8 inches in diameter showing abundant traces of fossils was found imbedded in the quartz at the bottom of a depression. In other cases the presence of the carbonate in such situations was proved by effervescence on the application of dilute acid.

The third general variety of blout quartz shows a pronounced brecciated structure, the whole being made up of sharply angular fragments, mostly less than an inch in diameter but often as much as three or four inches. The breccia is generally well cemented, and firmly bound together. The cementing material in most cases observed is quartz, but in some cases where the breccia has been exposed to the weather, the cement is etched, leaving the angular fragments in sharp relief. In these cases the cement proved to be, in part at least, carbonate of lime by testing with dilute acid. In the breccia with siliceous matrix the angular fragments are often free of color while the matrix is strongly colored by iron oxide and appears as a compact red or yellow jasper. All three of these varieties of blout quartz may occur together in the same mass.

The stratiform facies of the solid compact variety of the quartz has been alluded to. But the cavernous and brecciated varieties are often also stratiform. In this case the stratification is so similar to the stratification of the neighboring limestones, that no one in the field could have any doubt but that the quartz is the result of the silicification of that formation. Not only is the quartz stratiform, but the individual beds are quite distinct from one another and separate under the weather along the original bedding planes. When in such stratiform quartz, resembling an outcrop of limestone, one finds residual masses of fossiliferous limestone imbedded in it, in the bottom of depressions due to weathering, the evidence amounts to a demonstration that some of the blout quartz at least is the product of the silicification of the limestone adjacent to the intrusive porphyry.

This conclusion cannot, however, be extended with certainty to the solid, compact varieties of the blout quartz, which make up the greater part of the occurrence, and the stratiform appearance here may well be due to other causes than the replacement of an original sedimentary structure.

There is still another variety of the blout quartz which merits especial attention because its origin is not less clear than in the case of the cavernous, stratiform varieties with residuals of limestone. This is a light colored rock free from deep ocherous stains, although it may be distinctly yellowish. It possesses a prevailing spongy or cellular structure on weathered surfaces and tends to break down into fragments of small size which mantle the upper and flatter slopes of the porphyry areas. In consequence of the tendency to break down, this variety of blout does not present such bold croppings as in the case of the other varieties. It is found occasionally, however, as on the Minnesota claim, as a cap of some prominence on the summits of the hills. This variety of blout quartz occasionally shows traces of porphyritic structure and it passes by insensible gradations, representing stages of less intense silicification, into the well characterized porphyry.

It thus appears that the blouts, which form so prominent a feature of the porphyry areas, and which from their mapping, appear to be remnants of a discontinuous shell or envelope which once encased the porphyry, are in part the result of the replacement of the adjacent limestone, and in part the result of the extreme silicification of the porphyry itself on its margin, but in greater part can not with confidence be referred to either of these origins on the basis of direct evidence, although it seems probable from analogy that most of it is due to the replacement of limestone.

Relations to Copper Ores and Garnet Rock.—The more or less ocherous iron stain which affects most of the blout croppings has generally attracted the attention of prospectors to them and not a few pits have been sunk upon them. It is only rarely, however, that ore is found in these croppings and it is then, almost in every case, in the form of sparing quantities of malachite, azurite and chrysocolla. A little fresh pyrite is not infrequently found and it is the oxidation of this that gives the blout its ocherous appearance. A number of shafts which have been sunk in the blout appear to pass through it at no great depth. Some of these pass into a massive greenish or brownish rather soft rock, evidently a decomposition product, and then penetrate a garnet rock, or garnet and quartz, in which is usually found fresh chalcopyrite and pyrite, although in no great quantity. This is true of the Morris shaft near Pilot Knob, and of a shaft sunk on the Emma Nevada claim. A similar occurrence was found in the third level of the mine at Copper Flat, the gradation from the fresh garnet rock with some chalcopyrite into an olive brown or greenish decomposition product being perfectly apparent in the abundant material on the mine dump.

It is not proposed at this place to discuss the genetic relations of this garnet rock and its decomposition product to the quartz blouts; but it is well to note that the field evidence indicates that they are associated to the extent that there are bodies of garnet rock with chalcopyrite in the midst of the porphyry in the vicinity of, or beneath, the blout.

THE PORPHYRY AS A COPPER ORE.

Certain portions of the porphyry mass, notably at the Ruth Mine and at Copper Flat, have been so mineralized as to constitute an ore of copper. In considering the characteristics of this ore and its genesis, it will be first necessary to recognize the fact that the porphyry, considered as an ore, is, like most metalliferous deposits, separable into two zones: the zone of oxidation near the surface, and the unoxidized zone beneath this, extending to depths at present unknown. The porphyry of both zones may constitute a copper ore but each in a different way. At the Ruth Mine the porphyry of the oxidized zone is almost wholly if not quite devoid of sulphides. It has a prevailingly yellowish color, but is in many places of a deep red color due to the abundance of iron oxide. It carries never more than a small fraction of one per cent. of copper, and frequently none can be detected. The passage from the oxidized zone to the unoxidized is very abrupt and sharp, and, below the dividing line, the porphyry throughout the mine is bluish white, and is usually well sprinkled with crystals of pyrite and chalcocite of small size, probably averaging half a millimeter in diameter. The immediate appearance of these two sulphides at the dividing line between the oxidized and the unoxidized rock and their absence above that line leave no room for doubt but that these minerals formerly existed in the upper zone, and have been oxidized and leached out by meteoric waters descending from the surface.

While there is thus a very sharp line between the two conditions of the porphyry in the mine, that line is hypsometrically extremely irregular, and has no reference to the present level of the ground water. The water level stands in the mine at present at about 335 feet below the shaft mouth, and the mean lower limit of oxidation is somewhere between 100 and 150 feet below the shaft mouth. But the various levels and cross cuts of the mine have shown that tongues or wedges of oxidized rock extend irregularly down into the unoxidized zone as far as the 500-foot level, with occasional limonitic stains along seams to still greater depths. It appears to be clear from this state of affairs that the level of the ground water has been lowered probably not less than 250 feet and possibly much more in quite late geological time at such a rate that the oxidation process failed to keep pace with it; so that about a couple of hundred feet of the unoxidized zone has been left stranded, so to speak, above the water plane. The irregular tongues and seams of oxidized rock that project down into the sulphide zone, of course, merely represent the *loci* of more efficient oxidation by waters percolating down from the surface, in the general tendency of that process to overtake the retreating ground water.

This lowering of the ground water may be explained in more than one way. As will be shown later, the region has suffered deformation by faulting and tilting at quite a late date in its geological history and this deformation would, or at least might easily, have affected the position of the water plane. Again the district lies in a geological province which, as has been so well shown by Gilbert* and Russell,† has been affected in Quaternary time by an advent of arid conditions extending to the present, which may well be considered as an adequate cause of the lowering of the ground water throughout the Great Basin. In this point of view the descent of the water plane in the Egan Range would be the subterranean correlative of the last desiccation of Lake Bonneville. The discriminating test between the two suggestions above made as to the lowering of the ground water would be the generality of the phenomenon. If, in various mines distributed over the Great Basin, it should be found to be a fact that the ground water has in general been lowered to a similar extent, then local causes would be eliminated except as modifying conditions, and the general cause, the advent of arid conditions, would seem to be the true explanation. If such should prove to be the case, it would be an interesting addition to the accumulating facts which go to show a definite dependence of certain important features of ore deposits upon climatic conditions.

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* Lake Bonneville, U. S. G. S., Mon. I.

† Lake Lahontan, U. S. G. S., Mon. IX.

The temperature of the mine water at the bottom of the inclined shaft on June 15, 1904, was determined to be 16° C. A sample of the water had previously been sent to San Francisco and was there analyzed by Dr. Harry East Miller, with the result tabulated below. It is probable that the proportion of ferric sulphate is higher than is actually the case in the mine owing to the difficulty of preventing oxidation of the ferrous salt. The result is interesting as an indication of the materials which are being leached from the porphyry by the descending meteoric waters. There is no evidence or suggestion of ascending waters in the mine at present.

ANALYSIS OF MINE WATER AT THE RUTH MINE.

	Grains per Gallon of 231 cu. in.
SiO_2 + insoluble matter	5.50
$NaCl$	4.88
KCl	.55
$FeSO_4$	5.77
$Fe_2(SO_4)_3$	8.78
K_2SO_4	2.96
$CaSO_4$	20.99
$MgSO_4$	7.61
Organic matter + water of sulphates	6.96
	64.00

Another sample of the mine water, collected by the writer and analyzed in the mine laboratory as expeditiously as possible after collection, by Mr. Herbert Ross, gave the following results, for the ferrous and ferric sulphates:

$FeSO_4$	9.36
$Fe_2(SO_4)_3$	.4

From this it would appear that the iron of the mine water is nearly all in the ferrous state and that the high proportion of ferric sulphate in Mr. Miller's analysis is ascribable to oxidation in the interval between the taking of the sample and the time of his receiving it. If this be so, it clearly indicates a deficiency of oxygen in the mine waters, thus promoting the maintenance of a supply of SO_2 which, as has been so well shown by Winchell,* is favorable for the reduction of copper sulphate to cuprous sulphide and the precipitation of the latter as chalcocite upon pyrite. That the chalcocite is secondary upon the pyrite is very apparent in several samples of the ore that were examined, the chalcocite being frequently a shell encasing, or partially encasing, pyrite.

From what has thus far been stated it appears certain that the copper ore of the Ruth Mine, porphyry impregnated with chalcocite and pyrite in sporadic crystals, owes its value in part to secondary enrichment by downward leaching from the zone of oxidation. The fact that the oxidized zone might easily be robbed of its copper ore by the leaching action of sulphate of iron, was experimentally verified by placing a mixture of pulverized chalcocite and porphyry in a burette and causing a 10 per cent. solution of ferrous sulphate to pass through it in presence of the atmosphere. The chalcocite was taken into solution and passed from the burette as copper sulphate, $CuSO_4$, at a fairly rapid rate. While this secondary enrichment of the porphyry below the zone of oxidation is unquestionable, two important and significant facts remain to be noted. The first of these is that the products of this enrichment are not localized at any particular horizon in the porphyry, so far as the development of the mine has yet gone. The copper values are by no means evenly distributed in the ore bodies thus far blocked out. But the richer ground is apparently rather determined by freedom of flow of descending solutions, that is, by local structural conditions in the porphyry, than by any horizontal control such as the present level of the ground water. In so far as the sulphides are uniformly distributed, this may possibly be ascribed to a steady retreat of the ground water level, whereby the additional copper ore leached from above was distributed fairly uniformly over the range of that retreat, although at any given stage it was precipitated chiefly at the contact with the ground water. It is more probable, however, and more consistent with the distribution of chalcocite at Butte, Montana, that the products of the down leaching from the zone of oxidation were not precipitated at the ground water level, but more diffusely through the region of the ground water, in the course of a slow circulation, which is implied in the maintenance of a fairly constant level of that water in the face of additions from above. In this view we might expect below the level of the ground water an appreciable but very moderate enrichment of the ore as compared with the values in the still unoxidized ore above the ground water to which the mine developments are at present chiefly confined. This generally very moderate enrichment will doubtless be found to be greatly modified by structural differences affecting freedom of circulation of the ground water, and may only be detected when considerable bodies of the country have been blocked out so as to permit of a satisfactory average value, which may properly be compared with average value of the ore in the unoxidized ground above the present water plane. This zone of probable moderate enrichment might from the experience at Butte be expected to gradually decrease in value with depth.

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* Bull. G. S. A., Vol. 14, pp. 269-276, 1903.

The second significant fact to which it is here desired to advert, is that the ground which is being leached in the course of oxidation differs in no essential particular from that which is being enriched in consequence of that leaching. It has been shown that the line of contact between the oxidized and the unoxidized zones, while quite irregular, is exceedingly sharply defined and that the result of oxidation and its attendant leaching is simply to lower the upper surface of what may be termed the ore bearing country. It has been shown also that this irregular surface is far above the ground water. It thus appears clear that the oxidized rock was before oxidation simply the bluish white decomposed porphyry sporadically impregnated with pyrite and chalcocite. This ore then, which by oxidation has contributed secondary sulphides to the lower ground, must itself have been mineralized by a similar secondary process. In other words, the copper ore which yields by oxidation the materials for the enrichment of the lower ground, is not a primary deposit, but has been derived from some primary source not yet apparent; and our so-called secondary enrichment is in reality at least a tertiary enrichment. This conclusion immediately raises the question as to the original unenriched copper deposit, or the product of the primary concentration. The answer to that question cannot be given on the basis of direct evidence, but only as an inference from certain suggestive facts observed throughout the district.

The only primary deposits of copper that have been observed in the district are limited bodies of chalcopyrite intimately associated with garnet rock, or with garnet and quartz. These primary ores occur in two distinct situations. One of these is at the contact of intrusive rocks, particularly the monzonite and monzonite porphyry with the Carboniferous limestones. Here they are clearly referable to a process of contact metamorphism. By this is meant not merely thermal metamorphism, but reactionary metamorphism, whereby solutions bearing silica and iron from the intrusive mass react upon the lime carbonate and give rise to the lime-iron silicate, garnet. These same solutions appear to have brought with them the materials necessary for the deposition of the chalcopyrite, and sometimes there was an excess of silica which was precipitated as quartz.

The other situation in which primary copper ores have been detected is in the quartz blout and here again it is intimately associated with garnet. From considerations set forth in previous pages, it appears very probable indeed, if not a demonstrated fact, that the quartz blout is largely the result of a silicification of the limestone, chiefly on the periphery of the copper bearing porphyry, but also partly along fissures in the limestone in the vicinity of the porphyry. At the surface, and often for considerable depths below the surface, these ores are now in the form of the carbonates, malachite and azurite. But these carbonates are regarded as the result of the alteration of chalcopyrite *in situ*. In other localities, particularly at the Morris Shaft near Pilot Knob and at a pit near the road between Copper Flat and Pilot Knob, the quartz blout at depth carries considerable garnet, with pyrite and chalcopyrite. In the Copper Flat Mine on the 300-foot level there is an extensive body or so-called "dyke" of garnet rock with nests of pyrite and chalcopyrite. The garnet rock is for the most part thoroughly decomposed to a greenish or brownish material which, when moist, has a cheesy consistency and on drying on the dump, slacks in the air. All gradations may be observed between the perfectly fresh garnet rock and the decomposed material.

It thus appears that the only traces of primary copper ores in the district are in the form of chalcopyrite associated with garnet, and that certain of these occur in the quartz blout either as the original chalcopyrite or altered to carbonates.

On this basis the hypothesis may be favorably entertained that the secondary copper ore of the Ruth Mine has been derived from the downward leaching of copper from bodies and disseminated particles of chalcopyrite in the course of superficial oxidation of the blout in which they were originally deposited. There are at present vast bodies of blout at the surface immediately above the Ruth Mine, but these are only remnants. The greater part of the blout has been removed by erosion. The product of this leaching was deposited as chalcocite in the porphyry at a time when the water level was much higher than at present. And finally, when in consequence of the subsidence of the ground water to lower levels the zone of oxidation extended into the porphyry, this chalcocite was in turn taken into solution and redeposited as chalcocite at still lower levels. This, leaving out of account for the moment the source of the chalcopyrite, appears to be the history of the copper deposits in the Ruth stated broadly.

The modifying factors are the structural features. These fall into two categories. (1) The thoroughly sheared and internally deformed condition of the porphyry which while opening up the rock to the permeation of the ground water, with its mineral matter in solution, would render that permeation irregular and so give an irregular distribution of the values. (2) The presence of a dyke of dense fine textured minette to the northeastward of the present mine workings would undoubtedly affect the underground circulation, although what its effect upon the deposition of the ore may have been is not yet clearly apparent.

In order to get an idea of the average contents of the ore of the Ruth Mine, an analysis was made at the writer's suggestion by Mr. Herbert Ross of an average sample. In the development of the mine samples have been taken for assay every five feet of the ground traversed. As there are about 5,000 feet of drifts, shafts and crosscuts in the mine, the ore of all kinds was represented at the time of the analysis (1904) by about 1,000 samples. Of these every fifth sample was used in equal proportions and thoroughly mixed. By the process of quartering this was reduced to a convenient quantity and analyzed. Owing, however, to the adverse conditions under which the analysis was made, the results were not satisfactory except as regards the determinations of sulphur, 6.00 per cent., iron, 5.34 per cent., and copper, 2.61 per cent. These results show that on an average the ore of the mine contains 10 per cent. of pyrite and 3.25 per cent. of chalcocite. It is to be noted, however, that much is included in the sample taken which would not be regarded as ore and mined in regular mining operations, so that the average copper content of the actual ore is higher than the analysis shows and is probably about 3 per cent. The development of the mine and its carefully maintained assay chart show that there is a very extensive body of ore of this average value with considerable ground running well above the average, and in spots reaching 8 and 10 per cent. There are no well defined boundaries or limits to the ore body except the oxidized zone above and the dyke of minette on the northeast. This dyke is probably of limited thickness and under the general conditions of deposition of the ore above set forth, it should be regarded as of the nature of an interruption to the ore and not as its final limit, it being quite probable that the porphyry on the north side of the dyke below the zone of oxidation is impregnated with chalcocite just as it is on the south side. In fact, the general conditions of deposition lend much support to the belief that a large part of the porphyry mass below the zone of oxidation will be found to carry more or less copper and will be well worth prospecting, particularly where the capping of quartz blout is strongly developed.

At Copper Flat the general conditions are analogous to those at the Ruth. There is the same porphyry intrusive in Carboniferous limestones, and although, as the map shows, this area of porphyry is separate from that of the Ruth yet the two may be continuous in depth. The fact that, on its western border, the porphyry of the Ruth area plunges beneath the limestone, while that of the Copper Flat on its eastern border passes similarly beneath the limestones in the opposite direction, renders this subterranean continuity of the porphyry of the two areas quite probable. On the hills about Copper Flat there are remnants of a once extensive body of quartz blout. In general it is difficult to specify any significant difference in the general conditions affecting the porphyry and those which prevail at the Ruth. Yet in one important particular the porphyry regarded as an ore of copper is very different from that at the Ruth. This difference lies in the fact that, in the zone of oxidation, the copper ores, over a very considerable acreage at least, have not been leached out of the porphyry but have been fixed in the form of carbonates. Over an area of perhaps 10 acres numerous prospect pits have been sunk in the porphyry and show a very general impregnation of the rock with green and blue carbonates and carrying on the average an attractive percentage of copper said to range up to 7 per cent. Many of these pits are fairly deep and the dumps about them show that the copper carbonate extends to their bottom. Not having had access to the record of these prospect pits or to the assays of the samples taken from them the writer can form no very exact idea as to the depth and value of the ore. The exposures are, however, excellent and enough is apparent at the surface to warrant the statement that there is a vast tonnage in sight, both of unoxidized and of oxidized ore, that could be mined by steam shovel methods. Unfortunately the carbonates of copper disseminated as they are rather diffusely through the porphyry do not lend themselves to ordinary processes of concentration as does the chalcocite. In order to handle this ore, therefore, it may be necessary to resort to some leaching process.

The porphyry thus charged with copper carbonate has otherwise the character of the zone of oxidation at the Ruth, except perhaps, that kaolinization has not proceeded so far and that the rock is fairly strong and coherent. Between this zone of oxidation with its content of copper carbonate and the ground water, there is as in the case of the Ruth a certain depth of the sulphide zone in a dry condition down into which the oxidized rock extends irregularly. This sulphide zone both above and below the level of the ground water resembles closely that at the Ruth. It is a bluish white porphyry impregnated with pyrite and chalcocite. Locally it has in it nests of bronzy or brownish mica in foils of considerable size. The mica appears to be secondary and is said by the miners to occur in those portions of the porphyry where the content of the chalcocite is highest.

The upper part of the unoxidized zone at Copper Flat carries higher copper values than the deeper ground, and doubtless represents a zone of enrichment by downward leaching at a former higher stage of the water plane. The general average value of the ore in the unoxidized ground differs but little from that at the Ruth.

It is probable that the copper ore of the oxidized zone existed earlier as chalcocite, itself a product of secondary concentration, and that in the oxidation process an excess of carbonic acid determined the carbonatization of the copper ore disseminated through the rock. The presence of this carbonic acid may perhaps be ascribed to a later period of eruptive activity which gave rise to flows of rhyolite, remnants of which are to be found in the vicinity of Copper Flat.

With the exception of the mines at the Ruth and Copper Flat practically all other attempts at copper mining in the district have been made upon rather unsatisfactory and limited deposits of chalcopyrite either on the contact zones of the intrusive rocks or in the quartz blout.

A discussion of the porphyry considered as an ore of copper would be far from complete without some reference to what is perhaps its most remarkable feature. This is the contrast which its internal structure presents to that of the surrounding rocks. As has been shown in an earlier part of this paper the Carboniferous limestones have been folded; but the folds are open and there is no evidence of intense compression resulting in plication or shearing anywhere in the sedimentary terranes. Similarly the monzonite which is the earliest intrusive into these sedimentary rocks shows no evidence of deformation or of notable shearing. The same is true of the monzonite porphyry. The latest eruptive, a rhyolite lava, is similarly devoid of evidences of compressive stresses. All of these rocks are, it is true, traversed by faults but these are not numerous and do not in any case appear to have affected the internal structure of the rocks dislocated. It is probable that they are the local manifestations of general movements of the earth's crust in this part of the Great Basin occurring at a late date in its geological history. The ore bearing porphyry on the other hand, although occurring in comparatively small and definitely limited masses in the midst of these unaffected or but gently folded and broadly faulted terranes, is internally intensely deformed. In the series of long drifts and numerous crosscuts of the Ruth Mine, which the writer examined closely, scarcely a step can be taken without passing slips and shear zones in the body of the porphyry. These have quite variable orientations both as regards dip and strike, but in spite of this variation a series of observations in all parts of the mine shows an interesting general tendency. Of some 74 observations for the direction of the dip of these slips and shear zones, only nine were found to bear southerly. In all other cases the direction of dip was in some azimuth to the north of the magnetic east and west line. That is, the prevailing dip is in the direction of the general dip of the mass of porphyry considered as a whole. The angle of dip ranges from 10° to 75° and the average value of the 74 observations is 40°. Many of these slips and shears intersect one another, the abutment of older slips upon later ones being commonly observed. Many of the shear zones have a black gouge from a few inches up to about a foot or a foot and a half in width, the black color being due to the pulverization of the pyrite and chalcocite in the zone of crushing. In other cases, there is a notable deposit of these sulphide shears which has been made subsequent to the movement and which, therefore, shows no evidence of crushing. In those cases where the black gouge is present, it is most probable that the movement was progressive, the first rupture having afforded conditions favorable for the deposition of the sulphides, and the recurrence of the movement having effected their attrition, together with the adjacent porphyry. In some cases there are seams of fresh sulphides in the midst of the gouge. At the lower limit of the zone of oxidation it is not uncommon to find that the oxidation has extended downward along the slips and shears below the general limits of the zone. It appears thus that these structural features of the porphyry are important factors in the process of mineralization, and it becomes an interesting question to inquire into their origin. The contrast which is presented between the intensely broken and sheared porphyry and the unmoved condition of the surrounding country indicates at once that the cause of the movement is an internal one, intrinsic in the mass of the porphyry, and not either general or local earth movements. The fact that the prevailing dip of the slip planes and shear zones is in the same direction as the dip of the porphyry mass, though probably at steeper angles, indicates that the movement has been one of repeated and complex normal faulting, and that this faulting is but an expression of the tendency of the mass to adjust itself to a new and diminished volume. It is further clear that such a tendency would not have found expression in faulting, had the shrinkage of volume been uniform in degree and in time throughout the mass.

Our inferences thus lead us to a picture of the porphyry mass shrinking in volume unequally in different parts and at different times. The only cause that can be suggested for such a shrinkage of volume is a chemical change within the porphyry and an elimination of certain of its chemical constituents. This suggestion is well borne out by the abundant evidence of kaolinization and allied changes within the body of the porphyry as far as it has been yet explored. The change from orthoclase to kaolin, with the partial elimination of alkalies and silica and the addition of water, involves a very considerable diminution of volume, and since this process has been general throughout the porphyry, it seems reasonable to make it accountable for the shrinkage mass. The tendency to collapse as the process proceeded would be adjusted by slipping and shearing on normal fault planes and as these developed the mass would be rendered more and more accessible to permeating solutions.

The process of kaolinization is probably most commonly inaugurated by the attack of carbonated waters, whereby a portion of the alkalies is removed as carbonate, carrying off with it a portion of the silica in solution, in the form of alkaline silicate. It has been shown that the slipping and shearing of the mass of porphyry was progressive and the process of kaolinization was probably also progressive extending over a long period of time. If this be conceded, there is nothing violent in the assumption that the process may have started immediately after the solidification of the porphyry, the source of the carbonic acid being the decomposition of the surrounding limestones by contact with the hot intrusive mass. This, at least, is the hypothesis which the writer entertains to explain the chemically altered and mechanically sheared condition in which we now find the porphyry.

The hypothesis finds support in the fact that it affords at the same time a consistent explanation of certain other important phenomena connected with the porphyry, particularly on its periphery. It also suggests an adequate explanation for the original source of the copper ore and its associated pyrite. Under the hypothesis, the carbonic acid would be in the ascending waters arising about and through the recently consolidated porphyry, the ascending tendency being due to the disturbance of the equilibrium of the ground water of the region by the invasion of the intrusive mass. This ascending water charged with carbonic acid would inaugurate the kaolinization of the porphyry. Lime would be present in these waters in the form of the bicarbonate. Under these circumstances, certain chemical reactions would take place from the recognition of which there appears to be no escape. The potassium silicate formed in the course of the kaolinization of the orthoclase would react upon the calcium bicarbonate. Potassium bicarbonate would be formed and calcium silicate precipitated, thus:

$$K_2SiO_3+CaH_2(CO_3)_2=CaSiO_3+2KHCO_3.$$

The calcium silicate thus formed would in turn be decomposed by carbonic acid, with the precipitation of insoluble silica, thus:

$$CaSiO_3+H_2CO_3=CaH_2(CO_3)_2+H_2O+SiO_2.$$

These reactions were verified experimentally for the writer by Mr. Herbert Ross, and while it is not insisted that they represent the detail of what must be a complex series of chemical reactions, yet they indicate with great probability the source of the silica which is so abundantly found in the form of quartz blout on the periphery of the porphyry mass, and the general mode of its derivation from the porphyry. It accounts also for the secondary silica in the body of the porphyry. Moreover, since lime silicate is formed in the process above outlined, it may have been locally precipitated, in combination with iron, in such situations, on the periphery of the porphyry, as to escape decomposition by excess of carbonic acid and so give rise to the garnet rock found sporadically at the contact with the limestone and to some extent also in the midst of the quartz blout. Further, since the copper ores of the district are intimately associated with the porphyry, except for certain unimportant occurrences on the periphery of the monzonite which probably have an analogous history, there seems little escape from the conclusion that the copper was originally minutely disseminated through the porphyry in its unaltered conditon; and that the same ascending waters which robbed the porphyry of part of its silica to form the quartz blout also leached it of its copper, depositing it as chalcopyrite in the blout, whence by oxidation and the agency of descending waters it was carried down into the porphyry again and deposited as chalcocite, the permeation of the rock by such descending waters being greatly facilitated by the rupturing and collapse of the mass due to the kaolinization.

MINETTE.

In the underground work at the Ruth Mine there have been brought to light two occurrences of lamprophyres neither of which were detected at the surface of the ground. Both of these have the mineralogical characters of minette. The first occurs as a small dyke a few feet in width in No. 1 level east. The dimensions and extent of the dyke are difficult to determine since it has been affected by the various shearing movements in the porphyry, which it cuts. Its exposed width is about 3 or 4 feet. It strikes N. 45 E. and dips to the N.W. at 30° and conforms to the direction of the slip planes in this part of the porphyry. It is best seen at the first cross-cut east of the station on No. 1 level, but may be traced for perhaps 50 feet beyond this point.

The rock of the dyke is fine grained and has a dark pepper-and-salt gray appearance. It is traversed by quartz stringers in much the same way that the porphyry is but is not notably mineralized. Under the microscope it is readily seen to be composed of about equal proportions of brown biotite and feldspar in an allotriomorphic granular aggregate. The feldspar is untwinned and in all sections has a lower refractive power than the balsam.

The second occurrence of the minette is a finer grained, compact, bluish green rock, which, in the zone of oxidation, decomposes to a soft yellowish or brownish mass of almost cheesy consistency. The thickness of this mass is not known since the mine workings have not pierced it, and, owing doubtless to its soft decomposed condition, it can not be traced at the surface. It seems, however, to form a somewhat irregular wall limiting the ore-bearing porphyry to the northeast, thus forming an important element in the geology of the copper deposit. All of the mine workings in the copper-bearing porphyry lie to the southwest of it; but the main shaft of the mine and the upper levels to the east have penetrated it for some distance.

In thin section the rock appears as a microcrystalline mosaic of untwinned feldspar having a lower refractive power than balsam, throughout which are abundant shreds of brown biotite and numerous areas of secondary white mica. Besides this there are grains of a blue, pleochroic mineral with an enormous refractive power and a moderately weak double refraction. Its maximum polarization tints range from yellow of the first order to blue of the second order, while the orthoclase for the same thickness shows gray blue of the first order. The grains show extinction parallel to the direction of elongation where such elongation can be recognized. The sapphire blue color is not uniform but patchy in its distribution, and the pleochroism is from blue to colorless. The blue ray corresponds to the axis of less elasticity. Surrounding the grains of this mineral is usually a border of white micaceous mineral, evidently secondary, and derived in part from the grains which it envelops. These characters are those of corundum, and it thus appears that we have here to deal with a corundiferous minette, a fact which is of course suggestive of the possibility of finding a facies of the rock which might yield sapphires of value. Those revealed in the study of the thin sections are of microscopic dimensions; but inasmuch as sapphires have been found in similar rocks in Montana,* their discovery here is a hint which may some day be of service in the search for gems.

Besides the minerals above described there is considerable pyrite scattered through the rock in isolated crystals.

Chemical Composition.—The corundiferous minette, constituting as it does an important feature of the mine as a wall or barrier limiting the distribution of the actually developed ore body on the north, was subjected to analysis for the writer by Mr. Ross with the object of settling as definitely as possible its petrographical character and its possible relations to the ore-bearing porphyry. The results of the analysis are as follows:

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* U. S. G. S. 20th Ann. Rpt., Pt. III, p. 554 *et seq.*

ANALYSIS OF MINETTE.

SiO_2	53.69
Al_2O_3	25.86
Fe_2O_3	....
FeO	1.71
MgO	1.91
CaO	.65
Na_2O	.89
K_2O	8.11
BaO	.37
P_2O_5	.25
Fe	.88
S	1.01
CO_2	.11
H_2O	3.66
F	.07
	99.17

From this analysis the following percentage of minerals in the rock has been calculated as probably representing its composition although the estimate is not altogether satisfactory:

Orthoclase	31.
Albite	7.
Anorthite	1.
Biotite	17.
Muscovite	8.
Corundum	4.
Apatite	.2
Calcite	.2
Pyrite	2.
Kaolin	21.
Free Silica	8.
	99.4

From this it is evident that the rock, although much kaolinized, pyritized, silicified, and otherwise altered, is rich in orthoclase and biotite and corresponds in a general way with what might be expected of a much altered minette. The high content of alumina in the analysis can only be accounted for on the assumption that some of that oxide exists in the rock uncombined, thus confirming the microscopic detection of corundum.

RHYOLITIC LAVAS AND TUFFS.

In the general statement of the geology of the district it has been said that the latest rocks with which we have to deal are certain rhyolites and tuffs which were erupted after the geomorphic evolution of that region was well advanced toward its present condition. In the district as mapped there are two considerable areas of such rocks besides some outlying patches. The first of these is at Quarry Hill which occupies the western medial portion of Ocher Valley. The hill has a north and south extent of about 4,000 feet and a width of 1,500 to 2,000 feet. The volcanic rocks which compose it clearly rest upon the eroded surface of the Arcturus limestone and have a thickness of about 180 feet. The lava is not now connected with any eruptive vent, and is evidently the remnant of a much more extensive sheet which once occupied the valley, and doubtless was once continuous with an area of similar rocks about two miles down the valley near the old Ely stage road. One may completely encircle the hill without leaving the exposed Arcturus shale limestone; but on the northeast side of the highest part of the hill the limit of the lava is a fault which has dropped it down against the limestone. It is evident from the situation of this lava that, although, as will be shown later, the region has been deformed and faulted since its eruption, the valley which it occupies must have had locally pretty much the same general configuration as is now presented to us by resurrection due to removal of the greater part of the lava by erosion.

Three Members of Volcanic Series.—The section afforded by the abrupt faces of Quarry Hill shows that there are three distinct members in this volcanic accumulation. The first of these is a white tuff exposed at the base of the hill, on its east side. where the wagon road from the Ruth Mine to Copper Flat passes it. The rock is composed of fragments of pumiceous glass and rhyolite with broken crystals of quartz and feldspar. The fragments are usually small but some of them are a few inches in diameter. The tuff is rather firmly cemented. The full thickness is not exposed but it was estimated to be not less than 10 feet. To the north and northeast of Quarry Hill beyond the limits of the territory mapped, this tuff formation is well exposed in artificial and natural cuttings, and is there shown to be well stratified and to have a thickness several times greater than the estimate given above. The tuff has been quarried to some extent at various croppings for the building of fire boxes for steam boilers at the various mines of the district.

Above the tuff lies a sheet of black glassy porphyritic lava having the greasy luster of a pitchstone. This lava is best exposed on the north slope of the hill but its thickness could not be satisfactorily determined. It may be 40 feet. Above this the bulk of the hill is composed of a purplish red lava of lithoidal aspect with abundant phenocrysts of feldspar and black quartz. This rock extends to the summit of the hill where a small quarry has been worked which gives its name to the hill. This purple lava is traversed by structural planes of parting which appear to be parallel flow planes of the lava and dip to the northeast at angles of about 23°, indicating a tilting of the formation since its solidification. Traversing these flow and parting planes are several well marked jointages. The best defined system strikes N. 65° E. with a dip of 70° to the south-southeast. The next best defined system has a similarly steep dip to the southwest. In the absence of all suggestion or evidence of compressive stresses, these joints are most simply explained as due to relief from tensile stresses. There is no columnar structure in the rock.

At Copper Flat village and a little to the north of it there are three outlying patches of the purple variety of the lava lying partly on the Arcturus limestone and partly on the porphyry. The largest of these lies on both sides of the main street of Copper Flat but chiefly on the east side. It has a length from north to south of about 1,000 feet and a width of about 500 feet. Neither the black pitchstone nor the white tuff appear to be here present beneath the purple rhyolite.

The second important area of rhyolite is found on White Hill, the summit of which is about a mile and a half from Copper Flat to the southwest. This is a roughly triangular area, the longest side of which is to the north and is determined by a fault which has dropped the rhyolite against the porphyry, the Ely limestone and the Arcturus shaly limestone. It is nearly a mile in greatest length along the line of the fault. On the south side the purple rhyolite reposes partly upon the porphyry, partly upon the Ely limestone and partly upon the Arcturus shaly limestone. The thickness of the lava is estimated to be here not less than 300 feet. At its base where it reposes upon the older formations, no exposures were found of either the black pitchstone or the white tuff and it is probable that they are here absent from the section. The purple rhyolite of White Hill differs somewhat in detail from that described at Quarry Hill. It is of a more compact texture and a lighter color and shows a more pronounced flow structure. It breaks down readily into thin slabs or shaly fragments, a tendency which was not observed at Quarry Hill.

Petrographical Characters.—Hand specimens of the dark pitchstone variety of the rhyolite present the characters of a back glass thickly studded with sharply defined phenocrysts of vitreous to dull white feldspar, from 1 to 4 mm. in length, small dark quartzes and a few flakes of brown biotite. Under the microscope the ground mass is a stippled gray glass, the stippled appearance being due to the sporadic distribution of clusters of polygonal microlites and stellate trichites. The glass has a lower refractive power than balsam. In this glass are imbedded numerous phenocrysts of cracked sanidine, more or less corroded quartz, a little plagioclase and a few crystals of greenish brown biotite. The plagioclase is in some cases enclosed in the sanidine which also holds occasionally inclusions of glass. The sanidine has a small optic angle giving in isotropic sections a nearly uniaxial figure and a negative sign.

The more abundant variety of the rhyolite of purplish tint is composed of a compact ground mass in which are imbedded numerous vitreous phenocrysts of feldspar ranging in size up to 5 mm., and dark quartz rarely exceeding 3 mm. in diameter.

In thin section the ground mass is a turbid glass with numerous small vaguely defined doubly refracting areas. The feldspar is mostly sanidine with a little plagioclase. The quartz has well defined boundaries of the usual dihexahedral habit, but is occasionally somewhat resorbed. The microscope reveals a few foils of biotite not apparent in the hand specimens.

OBSIDIAN.

On the Josephine claim, near Versan's cabin, is a small exposure, not exceeding 30 feet in diameter, of obsidian, which appears to be intrusive in the porphyry. It is the only occurrence of the kind which has been observed within the area of the district examined, and is very probably connected with the volcanic activity which gave rise to the rhyolite flows, although there is no direct evidence bearing upon this correlation. In the midst of this exposure a wide pit has been sunk to a depth of perhaps 12 feet, and fresh obsidian is well exposed on the walls of the pit. Surrounding the exposure on all sides at the surface there is nothing but porphyry as far as can be made out from an examination of the soil and hillside wash. As the mantle of debris is here rather heavy, however, it is possible that the obsidian has a much greater extent than is revealed in the exposure. The actual contact with the adjoining porphyry is nowhere exposed.

The obsidian is a somewhat resinous looking, dark, vitreous rock which might from its luster be called a pitchstone. The most remarkable feature connected with the occurrence is that the rock contains numerous inclusions of dark altered shale ranging from half an inch to 2 or 3 inches in diameter. These inclusions indicate that the intrusion has pierced the White Pine shale in depth, and has derived its inclusions from that formation.

Under the microscope the obsidian appears as a brownish glass with a well marked flow structure containing occasional fragments of crystals of sanidine and quartz. Under high powers the glass appears whitish and the brown color is seen to be due to numerous brownish, irregularly shaped, ragged or flocculent inclusions. These are drawn out in lines and give the rock its flow structure. The glass has a lower refractive index than the balsam as is clearly indicated by the Becke test.

One of the fragments of shale inclosed in the obsidian was examined in thin section. The fragment was subangular and had dimensions about $1 \times 1\frac{1}{2} \times \frac{3}{4}$ inches. Its color was bluish black. The most interesting fact revealed was the evidence of thermal metamorphism shown in the presence of numerous crystals of chiastolite. The ground mass of the rock is murky and much obscured by particles of carbonaceous matter. Through this are disseminated small flakes of brown biotite. The chiastolite, in beautifully idiomorphic crystals with geometrically disposed carbonaceous inclusions, lies in this matrix. The sections are square, oblong and rhombic, and the carbon is arranged in the usual way so characteristic of chiastolite. The size of these chiastolites is generally about .5 mm. in longest dimension. The discovery of such pronounced evidence of thermal metamorphism under such conditions is most interesting as indicating that no greater time is required to effect such changes than is required for a magma to solidify as a glass—a period which is generally conceded to be quite short.

OTHER METALLIFEROUS DEPOSITS.

Before the Robinson Mining district became known as a prospective copper camp, various attempts had been made to mine lead-silver, and gold ores. Up to the present these attempts can not be said to have been successful in the sense of having led to profitable mining operations. But a considerable amount of capital has been sunk in the district in gold mines and an uncertain amount of selected ore has been shipped out from the lead-silver mines.

The writer has made no special study of these deposits and cannot, therefore, undertake their discussion here. It is desired, however, to call attention to certain features of these deposits, particularly as regards their relation to the ore-bearing porphyry. The lead-silver deposits form a fairly well defined belt confined to the Ruth limestone and lying to the north of ore-bearing porphyry and Lane Valley. The gold deposits occur in various Palaeozoic formations, particularly the Ruth limestone and the White Pine shale, and are distributed in a belt on the south side of the ore-bearing porphyry and Lane Valley although just beyond the area mapped there are some gold prospects on north of Lane Valley. This general distribution of the two kinds of deposits appears to the writer to be significant of a genetic relationship with the same porphyry which has given rise to the copper ore. In the vicinity of the Ruth Mine the gold ores have not been exploited to any notable extent and the writer has only seen the gossan of one deposit. The gangue is a silicified limestone more or less stained with ocher from the oxidation of pyrite. The deposit, so far as could be judged from the collar of a prospect pit, is disposed parallel to the stratification of the Ruth limestone. The writer was informed that the ore ran at $18.00 per ton but can not vouch for the fact.

This deposit lies in the limestone a little *below* the porphyry in which the Ruth copper mine is situated.

The lead-silver deposits to the north of the Ruth are *above* the porphyry. On the Phoenix claim a considerable amount of development work has been done and the character of the deposits can to some extent be observed. The ores are for the most part distributed along the planes of bedding in the limestone. The latter is inclined at quite low angles (18° to the N.E.) and mineralization has occurred at different stratigraphic horizons one above another. These successive sheets of ore are connected with one another by a vertical, mineral-filled fissure, and the tabular deposits so connected seem to pinch out at no great distance from the vertical vein. The tabular deposits near the vertical vein vary from one to three or four feet in thickness and the vertical vein was at one place observed to be two feet wide; but in both the vertical vein and the tabular deposits parallel to the strata the thickness varies rapidly. The occurrence of the ores in the deposits is, also, so far as could be observed, far from uniform. The prevailing color of the ore in the mass is light ocherous yellow and iron minerals appear never to have been abundantly represented in the deposits. The chief gangue is silica which appears to be a replacement of the limestone and the croppings at the surface resemble closely the quartz blout of the neighboring porphyry. Some of the limestone immediately adjacent to the deposits is of a dead white chalky character and is somewhat slickensided. It resembles massive kaolin but effervesces freely with acid. The siliceous vein matter carries galena, a sample of which was examined by Mr. Ross and found to contain 22.4 ounces of silver to the ton and $1.49 in gold. Besides the galena there are azurite, malachite, and chrysocolla in sparing quantities, a little cerussite and considerable calamine. With the quartz of the gangue are also chalcedony, opal, fluorspar, and calcite. There are also some dendritic films of manganese oxide.

While in general the chief feature of the mineralization has been the silicification of the limestone, there is abundant evidence of minor fracturing and crustification and much of this has occurred after the chief deposition of silica.

From the general facts above set forth, it appears that in the vicinity of the Ruth, without considering the mines farther east, there are three well marked zones of metalliferous deposits, viz.:—

1. A central one containing sulphides of iron and copper *in* the porphyry.
2. A southern one carrying gold in the limestones *below* the porphyry.
3. A northern one carrying argentiferous galena with subordinate zinc and copper minerals in the limestones *above* the porphyry.

The segregation of the metals in this stratigraphic or structural relation to the porphyry is a most interesting fact but with the limited data available it would be perhaps unwise to attach too much significance to it. The fact is here recorded in the hope that it may prove useful when considered in connection with similar observations elsewhere in sufficient abundance to lead to an inductive hypothesis.

FAULTS.

The general structure of the district, particularly as regards the folding of the Palaeozoic strata, has been briefly described in an earlier part of the paper. The essential features of the structure are the Ruth syncline with an axis pitching northerly, the rather flat Saxton anticline pitching southerly flanking this on the west, and the broad spreading Rib Hill anticline, pitching to the southeast, flanking it on the west. These folds appear to have been established before the advent of the earliest intrusive, the Weary Flat monzonite, which appears in the axis of the Rib Hill anticline cutting across the folded strata. The simplicity of these folds is interrupted by the more or less continuous belt of ore-bearing porphyry which traverses the district with a trend in general transverse to the strike of the sedimentary strata. It is probable that the rupturing of these folded formations, incident to the injection of the intrusive masses, was accompanied by more or less pronounced dislocations; but such dislocations were more of the nature of laccolithic lifting of the formations, one part from another, than of faults in the usual sense of the term.

The only true faulting subsequent to these intrusions that has been detected in the district is of very late date, since the faults traverse the sheets of rhyolite which were poured out over the surface at a time when the latter had been reduced by erosion approximately to its present general configuration. These rhyolitic lavas may be early Pleistocene and are certainly not older than late Pliocene, judging from the degree of degradation which the region has suffered since their extravasation. It is, therefore, believed by the writer that the faulting is not older than early Pleistocene.

Of these faults traversing the district perhaps the most prominent in the geological mapping is that which crosses the northern flank of White Hill and throws the rhyolite capping of that eminence down into the Palaeozoic rocks. This fault has a general northeast-southwest trend, and the mapping shows that it hades to the southeast at a small angle from the vertical. This is the direction of the down throw and it is thus a normal fault. The down throw brings rhyolite against the Arcturus and Ely formations and against the ore-bearing porphyry. The minimum estimated value for the amount of the down throw is 200 feet and it may be much more than this, depending upon the reduction which the surface on the upthrow side has suffered since the faulting transpired.

To the northeast, in the vicinity of Copper Flat the fault has dropped the ore-bearing porphyry against the White Pine shale, and the northeastern boundary of the porphyry has thereby been heaved to the northeast, a distance of about 3,000 feet.

A second fault of some importance is that which traverses Ocher Valley with a general east-west trend and drops the rhyolite of Quarry Hill against the Arcturus limestone. The throw here is downward on the south side of the fault and its minimum amount is about 100 feet. This fault curves somewhat on its strike and if continued for about half a mile beyond the point where the dislocation is apparent on the northeast face of the Quarry Hill, it would converge upon the White Hill fault in the vicinity of Copper Flat. In attempting to follow the fault to this intersection, it was found that the fault appears to fade out and no dislocation was observed of the west boundary of the Quarry Hill area of rhyolite. Followed to the eastward the fault is observable in the dislocation of the quartz blout near the grade up from Ocher Valley to the Ruth Mine. The trend of the fault from this point would be toward the Ruth Mine and it is possible that the precipitous bluffs which rise above the mine are in some way an expression of this fault, but no dislocation of the rocks could be here detected. Beyond the mine, however, there is an obscure line of dislocation of the quartz blout, porphyry, and limestone, extending from the northeast corner of the Ruth claim to the east end line of the Kimbley claim.

The remarkable geomorphic character of Lane Valley and the stratigraphic relations of the formations on either side of the valley suggest that the course of the valley has been determined by a fault; but as the valley is deeply filled now with alluvium, the nature of the fault, if such there be, is obscure and difficult to decipher. In the lower part of Lane Valley beyond the limits of the map, there is an important fault transverse to the trend of the valley, the dislocation of the strata being observable on the precipitous north side of the valley. The alluviation of Lane Valley is probably due to a disturbance of the drainage caused by this dislocation. Below the flat-bottomed alluviated portion of the valley, the drainage is through a rather steep grade, rocky gorge.

Besides these more important faults, a number of minor dislocations were observed, but they could not be traced for more than short distances and they do not appear to be factors in the structure which call for more than the briefest mention. One of these is on the east flank of Rib Hill; a second crosses a gulch about 500 yards west of the head of Lane Valley with a north and south trend and is best seen in a tunnel which has been driven on the west side of the gulch; a third lies about 400 yards west of Copper Flat and appears to be a spur or branch from the main White Hill fault already noted; a fourth lies about 800 yards northwest of the Saxton mine and brings the Ruth limestone in abutment upon the White Pine shale and a similar fault occurs on the north side of Lane City.

MINERALOGY OF THE DISTRICT.

In addition to the minerals enumerated in the petrographical descriptions of the rocks of the district, the following minerals have been encountered and are here summarily listed with brief notes for convenient reference, in the expectation that the list will grow larger as the district becomes better known.

Pyrite in small cubes and pentagonal dodecahedra common in the ore-bearing porphyry and minette below the zone of oxidation.

Chalcopyrite in nests and irregular masses usually associated with garnet at the contact of the monzonite with limestone and shale and in the quartz blout of the ore-bearing porphyry.

Chalcocite the valuable copper ore of the district, and so far as known confined to the ore-bearing porphyry below the zone of oxidation through which it is disseminated in small grains.

Native copper found rarely in the ore-bearing porphyry of the Ruth Mine.

Chrysocolla occurs to a limited extent in the ore-bearing porphyry and more abundantly in croppings of ore in isolated bodies of quartz blout, and then associated with the carbonates of copper.

Azurite in the superficial or oxidized zone of the ore-bearing porphyry at the Copper Flat mines and in various isolated croppings of quartz blout.

Malachite same occurrence as azurite.

Chalcanthite as incrustations of current formation on moist surfaces of the ore-bearing porphyry protected from the rain.

Melanterite same occurrence as chalcanthite.

Olivenite (?) a green mineral determined qualitatively as a copper arsenate. A rare occurrence in the Ruth Mine.

Turquois occurs sparingly in the ore-bearing porphyry of the Ruth Mine.

Galena occurs somewhat abundantly in silver-lead deposits to the north of the Ruth and to the north of Lane Valley.

Molybdenite thin films in the minette of the Ruth Mine.

Calamine found rather commonly in the zone of oxidation of the silver-lead deposits to the north of the Ruth.

Fluorspar gangue mineral of the silver-lead deposits and also in nests in the ore-bearing porphyry near the head of Lane Valley.

Calcite a gangue mineral in the silver-lead deposits.

Magnetite in considerable bodies at the Ruth, Copper Flat, and Pilot Knob at the contact of the ore-bearing porphyry with limestones. Apparently only on the lower side of porphyry intrusive.

Limonite same occurrence as magnetite but more limited: also common in the oxidized zone of the pyritiferous rocks.

Garnet common at the contact of monzonite, monzonite porphyry, and ore-bearing porphyry with limestones; both light yellow garnet, grossularite, and a red lime-iron garnet, andradite, occur. The andradite also occurs in the quartz blout below the zone of oxidation.

Chiastolite in fragments of black metamorphic slate enclosed in obsidian on the Josephine claim.

Rhodochrosite; presence inferred from the pink color of certain limestones which weather to a brownish black color and give reactions for manganese.

Wad rarely found in the porphyry of the Ruth Mine.

Talc occurs in a notable body in a tunnel run into the ore-bearing porphyry on the west side of a gulch about 500 yards west of the head of Lane Valley.

Gypsum occurs as a current deposition on the rubble of certain dumps near the head of Lane Valley.

Opal sparingly in small veins in silver-lead deposits.

Biotite a notable occurrence in the form of nests in the ore-bearing porphyry in Copper Flat mines and to a much less extent in the Ruth Mine.

University of California,
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Vol. 4, No. 15, pp. 359-396 ANDREW C. LAWSON, Editor

I.—CONTRIBUTION TO THE CLASSIFICATION OF THE AMPHIBOLES.

II.—ON SOME GLAUCOPHANE SCHISTS, SYENITES, ETC.

BY

G. MURGOCI.

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INTRODUCTION.

Recent researches on the amphiboles have shown quite clearly that in this important group of minerals, especially in the monoclinic series, there are still many questions to be solved. The amphibole family is far from having the same simplicity and clearness in classification, the same facility in the identification of minerals and names, or the same precision in the physical and chemical properties of the species, as the equally important families of the feldspars and pyroxenes.

This comes naturally from the complicated chemical constitution, and from the difficulty of bringing into close and continuous relation the physical properties and the chemical composition of these minerals. Yet, when we try to introduce order into this group, taking as our basis either the chemical composition or the optical or other physical properties (*e.g.*, etch-figures, etc.), we find ourselves confronted by very many species, subspecies, and varieties, where often the different individuals studied are variable in their composition and properties, forming intermediate terms not easy to classify.

Isolated mineralogical investigations of different members of this family, whether well crystallized or not, occurring frequently in small quantities, differing from each other in locality, in occurrence, and in genesis, will hardly give the possibility of a natural classification. We should much more easily attain results by an investigation of these minerals when they occur in a series of rocks from a petrological province. Following the changes in the mineralogical and chemical composition of the rocks, we can learn the variation which the minerals themselves undergo, and perceive the direction of the variation in their chemical composition and physical properties. Such a study must include, besides a precise and detailed determination of the physical properties, also a series of exact chemical analyses of the individuals studied.

During a visit to America I had the opportunity of studying two important series of rocks with amphiboles: rocks with riebeckite (from Massachusetts, Dobrogea, etc.); and rocks with glaucophane (from California). These two series comprise large numbers of rocks with various amphiboles from hornblende to riebeckite, or from actinolite to crocidolite. In these investigations defects which the classification and nomenclature of the amphiboles present become evident, yet I was fortunate enough to find some facts which throw light on the whole question. It has become clear that the determination of even the most common amphibole must not be limited merely to the measurement of the extinction angle and pleochroism.

Although my investigations have not been conducted according to the plan mentioned above, I wish to present in the following pages the results obtained in the glaucophane series. The rich material which I used in these investigations has been put at my disposal by Professors J. Perrin Smith (Stanford University), Andrew C. Lawson (University of California), and Charles Palache (Harvard University), to whom I wish in this place to express my heartiest thanks. Especially in frequent consultations with Professor J. P. Smith, who has accumulated the richest and most interesting collection of glaucophane and lawsonite rocks, much light was thrown on the subject. Further, some ideas have been generously suggested to us by Dr. A. C. Lane, who several years ago made, but did not publish, some observations in this field.

I.

AMPHIBOLES OF THE GLAUCOPHANE SCHISTS.

In the glaucophane schists and some other rocks from California which I had the opportunity of investigating may be distinguished many amphiboles which show a color and pleochroism in blue, violet, or green more or less pronounced. Two or more of these amphiboles may occur at once in the same rock and slide, and often one single lamella has zones or patches of two or even three amphiboles quite different from one another. Of course the separation of one type for a detailed chemical and physical investigation is almost impossible. Slight variations in the properties of the same amphibole are general and obvious under the microscope; thus it is very difficult to determine the chemical composition of one type, and if one has an analysis of an amphibole separated from a given rock, one cannot always be sure to what variety it would best correspond.

The nomenclature and classification which it is sought to establish here are made on the basis of the best analyses available, together with an exhaustive determination of the optic properties (under the microscope), and with a careful study of the literature on the minerals. I have distinguished: (gastaldite) glaucophane, crossite, crocidolite, rhodusite, karinthine soretite (?), lancite, actinolite, etc. Actinolite, karinthine, and glaucophane seem to form, as E. Weinschenk* has stated, a series from lime-magnesian to soda-aluminous amphiboles; the others seem to come in some side ferruginous series; this is quite certain for gastaldite—glaucophane—crossite—rhodusite—abriachanite.

Now it is generally admitted that blue amphiboles or amphiboles with blue pleochroism contain more or less alkali (soda) in their constitution; this is always the case with the amphiboles from glaucophane rocks.

Further, many petrologists have observed that some green amphiboles become bluish at the periphery, and also undergo some changes in their birefringence. Dr. A. C. Lane attributed this phenomenon to the increase of the soda content, and has given an empirical formula which connects the birefringence with the soda content of the mineral. It seems to me that this formula is not applicable in general, especially not in the glaucophane series. The chemical constituent with the most influence on the physical properties seems to be Fe_2O_3 (*viz.*, $Fe_2Si_3O_9$), and that not only in the glaucophane series, but in general in the amphibole family.

We know that the optic orientation, the optic constants, and the pleochroism vary very much in the alkali amphibole group from one member to another; but we can state that the pleochroism always varies on c' to blue, on b (axis of symmetry) to green, on a to yellow, whatever the orientation of the ellipsoid of elasticity may be.

Further, the size of the angle of the optic axes, the position of the axial plane, and even the angle of extinction, up to a certain point, are in relation with the amount of Fe_2O_3.

A. GLAUCOPHANE—CROSSITE—RHODUSITE.

Gastaldite—Glaucophane.—There is a very extensive literature about glaucophane, so that its identification is in general not difficult. It is well known, however, what a variation glaucophane shows both in its optical properties (extinction angle, pleochroism, birefringence, optic angle, etc), and in its chemical constitution.

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* E. Weinschenk. Die gesteinsbildende Mineralien 1901. Amphibolgruppe.

As regards the chemical composition, the ideas of G. Tschermak are generally admitted, namely: isomorphic mixtures of $Na_2Al_2Si_4O_{12}$, $(Na_2Fe_2Si_4O_{12})$, and $(MgFe)SiO_3$. A recalculation of all the analyses* of glaucophane and related minerals (Table I) shows that Al and Na do not behave as if they were in a single formula of a double metasilicate. In the gastaldite of Strüver, in the glaucophane of Yoshida, etc., Al_2O_3 enters with the coefficient 21, Na_2O with only 10. If Al and Na are in one single formula, their coefficient must be equal, which in general is the case with the other glaucophane analyses. We find again the independence of Na_2SiO_3 from $Al_2Si_3O_9$ in the abriachanite, crocidolite in the riebeckite series, etc.

In the same way the consideration of FeO, MgO, CaO, forces us to admit the direct and independent mixture of single formulæ $FeSiO_3$, $MgSiO_3$, $CaSiO_3$, as well as H_2SiO_3, the importance of which Berwerth and others emphasized years ago.

Further, Table I shows that Strüver has defended with good reason the view that gastaldite (I) is different from glaucophane, although the optic properties are almost the same. It is easy to see that the constitution of

$$\text{Gastaldite is} \left\{ \begin{array}{l} Na_2SiO_3 \\ FeSiO_3 \\ 2Al_2Si_3O_9\text{; and Glaucophane is} \\ (MgCa)SiO_3 \\ H_2SiO_3 \end{array} \right. \qquad \left\{ \begin{array}{l} Na_2SiO_3 \\ FeSiO_3 \\ 2(MgCa)SiO_3 \\ Al_2SiO_9 \\ \pm H_2SiO_3 \end{array} \right.$$

$$Mg : Ca = 5:2 \qquad\qquad Mg:Ca = 6:1$$

$$\text{or } (R'_2)_2\, R''_2\, (Al_2)_2\, (SiO_3)_{10} \qquad \text{or } (R'_2)_2\, (R'')_{33}\, Al_2(SiO_2)_8$$

$$\text{where } R' = Na + H \text{ and } R'' = Fe + Mg(+Ca)$$

Gastaldites or glaucophanes containing Al only are very rare; they have faintly or moderately intense colors and absorption, small angle of extinction (0°–6°), large (40°–60°) angle of the optic axes, with negative acute bisectrix.

In general some Fe replaces the Al and, as we shall see farther on, the properties vary much and the varieties have been given names, as crossite, rhodusite, abriachanite, etc.†

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* In table I, are represented the analyses by the molecular proportions of the constituent oxides, obtained from the percentages divided by the respective molecular weights of the oxides.

† The alkali amphibole studied by A. Johnsen (Neues Jahrbuch 1901, II. p. 117) is related more nearly to gastaldite than to glaucophane, as Johnsen emphasizes (see XXI Table I). It is a lime free gastaldite with Al:Fe = 4:3, Fe:Mn = 2:1, and poor in alkali, a member intermediate between riebeckite and gastaldite.

In the Californian rocks I have met with many glaucophane-like amphiboles very faintly colored, with small angle of extinction and variable axial angle, but as we have no analyses of them I do not know if they may be identified with gastaldite. In fact, there was no difference from the gastaldite of St. Marcel, etc. (slides in collection of Dr. Palache), which I have investigated.

As type of the glaucophanes for the Californian rocks, I consider the blue hornblende from North Berkeley (XI) described and analyzed by W. C. Blasdale.* I had the opportunity of seeing the original specimens, and of verifying and completing the optical determination of Blasdale. Pleochroism brillant: $\mathfrak{c}$ = azure blue, $\mathfrak{b}$ = violet to purple, $\mathfrak{a}$ = yellowish to colorless; $\mathfrak{c} \gg \mathfrak{b} > \mathfrak{a}$. Angle of extinction on clinopinacoid, $\mathfrak{c}:c = -5°$; on cleavage lamellae about $-8°$ (in the most deeply colored even more); birefringence as usual; 2 V not very large. The first bisectrix (negative) is almost perpendicular to the orthopinacoid.

Blasdale has, however, analyzed another glaucophane (XII) which is in some respects different from others. It is a very dark blue-violet glaucophane, which occurs in large prisms apparently homogeneous and pure, but showing under the microscope many patches of green amphibole (actinolite or karinthine) just as in crossite described by Palache. Sp. gr. 3.119–3.116. Pleochroism: $\mathfrak{c}$ = dark Prussian blue, $\mathfrak{b}$ = intense violet, $\mathfrak{a}$ = yellowish: $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. Angle of extinction on clinopinacoid, $-8°$, on cleavage lamellae, $-11°$ but variable with the intensity of the color: in some faintly colored specimens only $-9°$, in others very intensely colored up to $-13°$. It extinguishes in the same direction as the green amphibole, which has an angle of extinction of $-18°$. Birefringence: $\gamma - \alpha = 0.018$, somewhat smaller, $\gamma - \beta$, however, very small; 2 V very small, some lamellae being *uniaxial negative*. The axial plane is parallel to the plane of symmetry, the first (negative) bisectrix being almost perpendicular to (100).

The analysis indicates, as compared with the former, a decrease in Al_2O_3, and some increase in Fe_2O_3. The increase of Na_2O compensates for the decrease of MgO and CaO.

Glaucophanes with very small optic angles, or sometimes even uniaxial, occur frequently in the glaucophane schists of California, and some are faintly colored. Unfortunately there are no analyses of these varieties to show us precisely in what the chemical variation may consist. We can discuss the question from the chemical point of view better after the consideration of the next minerals.

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* W. C. Blasdale. Contribution to the Mineralogy of California. Bull. Dept. Geol. Univ. Cal., 1901, 2, p. 327.

The constitution of the uniaxial glaucophane is that of a glaucophane with Al:Fe = 3:1, *viz.*:

$$\left\{\begin{array}{l} \mathrm{Na_2SiO_3} \\ \mathrm{FeSiO_3} \\ \mathrm{2MgSiO_3} \\ \mathrm{(Fe'''Al)_2Si_3O_9} \\ \mathrm{H_2SiO_3} \end{array}\right. \qquad \mathrm{Mg:Ca} = 6:1 \qquad \mathrm{Al:Fe} = 3:1$$

Crossite.—Charles Palache gave the name of crossite to a blue amphibole-like glaucophane, which occurs in an albite schist in the hills near Berkeley.* The chief property of crossite, which on the original section I have determined independently of former observations, had been remarked already some ten years ago by Dr. A. C. Lane, but has never been published. In the last edition (IV) of Mikroskopische Physiographie I, Bd. II, Hälfte, H. Rosenbusch gives almost the same properties determined on specimens presented by Palache. My determinations were made on the original sections just at the time of the publication of that book and were communicated to Professor Rosenbusch in a letter.† Later I had the opportunity of finding this interesting mineral in several rocks of the Coast Ranges of California, sometimes with characters even more distinct than in the original sections. (See the material studied.)

The properties of crossite are so important for the general question of the amphiboles that I shall give more details here.

The chief property of crossite is that the *plane of the optic axes is perpendicular to the plane of symmetry,* the optic normal making an angle of -16° with the vertical *c*′ axis. Accordingly the pleochroism, which is identical in its colors and crystallographic orientation with that of glaucophane, is: $\mathfrak{a}$ = brilliant yellow, $\mathfrak{b}$ = dark Prussian blue, $\mathfrak{c}$ = dark violet. Very strong absorption, $\mathfrak{c} = \mathfrak{b} > \mathfrak{a}$, sometimes $\mathfrak{b} > \mathfrak{c}$, and almost opaque.

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* C. Palache. On a new Soda Amphibole, etc. Bull. Dept. Geol. Univ. Cal., 1. p. 181.

† Rosenbusch's observation, *loc. cit.*, p. 246-247; my communication, p. 395.

The color and absorption on one hand, the strong dispersion on the other hand, make the determination of the optic orientation and of the color of birefringence very difficult. The use of the gypsum plate is to be recommended, but at the same time the determination should be controlled by the mica plate, and especially by the character of the figure in convergent light.

The angle of extinction is difficult to determine in white light because of the dispersion of the optic normal, besides the horizontal dispersion of the bisectrix ($\mathfrak{b}_\rho : \mathfrak{b}_v = 6°$). Palache gives $\mathfrak{a} : \mathfrak{c} = 13\tfrac{1}{2}°$; Rosenbusch gives $\mathfrak{b} : \mathfrak{c} = -20°$ (max. $-30°$). I have determined in different specimens $\mathfrak{c} : c = +71°$ max. $74°$), or $\mathfrak{b} : c = -19°$ (in Palache's slides, $-16°$). It is certain, however, as in glaucophane, that the maximum angle of extinction measured in the slides does not correspond to the angle on (010), but to a plane near the prism face, as Daly has demonstrated. Measurements on cleavage lamellae gave 15°–20°, according to the color and the size of the angle of the optic axes.* $\gamma - \alpha = 0.008$. $\gamma - \beta =$ variable, very small. The axial plane is almost parallel to the base; both pinacoid sections show a cross (by using the oil immersion) which by rotation of the stage passes over into a hyperbola with widely separated arms. The angle of the optic

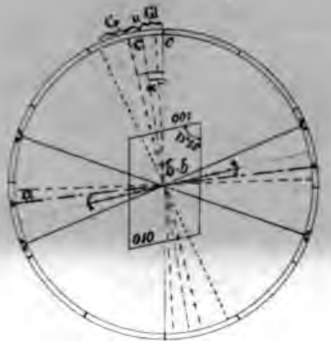

Fig. 1.—Stereographic projection on (010) of the optical orientation of common glaucophane Gl, uniaxial glaucophane **u**, and crossite Cr.

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* We often find in the literature glaucophanes with large angle of extinction (16°–20° in glaucophane of New Caledonia and M. Vanoise, 21°–28° in glaucophane of Syra and Saasthal, and even more), but we do not know either the chemical composition or the exact optic properties of these.

axes is variable, in Palache's specimens very large, so that the determination of the optic character is not easy, but for blue plainly negative; Rosenbusch's specimens show 2 V large, character negative; in some other rocks (see the material studied) I have found crossite with quite small optic angle, character negative, obvious in the orthopinacoidal sections. The sections perpendicular to an optic axis may be recognized by their very intense blue-violet color, of course with little or no pleochroism; on account of the dispersion there is no extinction.

The dispersion is so strong that it appears even in parallel light; $\rho > v$; $\mathfrak{b}_\rho : c > \mathfrak{b}_v$ (almost 6°). The hyperbolæ which appear in convergent light in the sections near or perpendicular to an optic axis are composed of several broad colored bands, red and blue very distinct.

A glaucophane with transverse axial plane (like crossite) has been described by Michel Levy* in a schist of Versoix (Genève). The pleochroism is like crossite, in blue and violet, but the angle of extinction only 3°; the first, negative bisectrix almost perpendicular to (100). $\gamma - \alpha = 0.021$; $\gamma - \beta = 0.003$; $2V = 35° - 40°$; optic character negative.

Another amphibole with the properties of crossite, except the strong absorption, has been described by F. Becke† in a green schist from Lämmerbüchl (Duxer Thal). I have seen this mineral, and can state that only the intensity of the colors is different. Pleochroism: $\mathfrak{c}$ = dark blue to violet, $\mathfrak{b}$ = dark greenish blue, $\mathfrak{a}$ = yellowish green. $\mathfrak{b} = \mathfrak{c}$; $\mathfrak{b} : \mathfrak{c} = -18°$ ca.; $\mathfrak{b}_\rho : c < \mathfrak{b}_v : c$; $2V = 90°$. $\gamma - \alpha = 0.01$ca. The dispersion of the optic axes $\rho < v$. All these properties are exactly the same as I have determined for the crossite from the Coast Ranges of California. Further, the origin and occurrence of Becke's crossite is the same as that from California.

The analysis of Palache's crossite, made by W. S. Tangier Smith, shows in comparison with Blasdale's analyses and those by Washington, etc., of the glaucophane from Syra, Zermatt, etc., only this difference (except water) that Al:Fe = 3:4. The constitution is that of a glaucophane:

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* In Barrois' paper, Mem. sur les Schistes met. de l 'île de Groix. Ann. Soc. Geol. du Nord, Lille, 1883, II., p. 50.

† F. Becke. Über eine merkwürdige Hornblende. Tscherm. M. und P. Mittheil, 21 p. 247, and Rosenbusch's Mikroskopische Physiographie I. II. A, p. 247.

$$\left\{\begin{array}{ll} Na_2SiO_3 & \\ FeSiO_3 & Mg:Ca = 6:1 \\ 2MgSiO_3 & Al:Fe = 3:4 \\ (AlFe)_2Si_3O_9 & \end{array}\right.$$

as P. Groth* has stated; but because of the characteristic properties and chemical constitution, I propose to retain the name *crossite* for such glaucophanes with transverse axial plane. I add here that this little variation in the chemical composition (Fe ⩾ Al) has a great influence on the cohesion, so that crossite gives etch-figures quite different from those of glaucophane.

Dr. A. C. Lane has remarked (in a letter to Dr. Palache, November 27, 1895), and I can confirm the observation, that crossite is not identical with Cross's amphibole.† Cross has identified, with good reason, the blue amphibole of Silver Cliff with Lacroix's crocidolite.‡ I was not fortunate enough to find schists with crocidolite, such as have been described by Lacroix, S. Franchi,§ C. Smith,‖ etc. Professor Louderback has shown me, however, a quartzite with crocidolite (?) (from the Coast Ranges) which is very similar to the description of Lacroix. I may add, however, that among the crocidolite-like minerals there are several kinds of amphiboles.

Rhodusite (*Abriachanite*).—Almost all mineralogists have considered Foullon's rhodusite** as being related to glaucophane. Foullon himself describes it as an asbestos variety of glaucophane. According to the occurrence (in a "breccia" and in the "Asbest-artiger" schists of eocenic flysch) form and few properties given, and especially according to the analyses, rhodusite is a member of the glaucophane group of amphiboles related to crossite and crocidolite, as Rosenbusch has emphasized in his new book. One can see (in Table I) that rhodusite is the Fe-end member of the glaucophane series. Its constitution is that of a glaucophane where Al is replaced by Fe:

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* P. Groth. Tableau des mineraux d'après leurs composition chimique, 1904. Edition Pearce and Jourowsky.

† W. Cross. Note on some secondary minerals of the amphibole and pyroxene groups. Amer. Jour. Sci., XXXIX. May, 1890.

‡ A. Lacroix. Sur la crocidolite. Bul. d. l. Soc. de Mineralogie, Paris, 1890. XIII. 10. Mineralogie de la France, p. 691, 1893.

§ S. Franchi. Contrib. allo Studio delle roccie a glaucofane. Extr. del. Bollettino del R. Comitato geologico, 1902. No. 4.

‖ C. Smith. Untersuchungen einiger Gesteine. Zeits, für Kryst. 1904, 38, p. 201.

** In Bukowski's paper in Sitzungsberichte d. k. Akademie, Wien 1890, p. 226. H. B. Foullon, Ibidem, 1891, 100 p. 169.

$$\left\{\begin{array}{l} Na_2SiO_3 \\ Fe''SiO_3 \\ 2MgSiO_3 \\ FeSi_3O_9 \\ H_2SiO_3 \end{array}\right. \qquad \text{(very little Ca.)}$$

It is a pity that, except pleochroism like that of glaucophane and an uncertain angle of extinction (4° ?), we possess no other properties of this interesting end member of the glaucophane series.

We find in the literature (Hintze p. 1267, Dana p. 401) another mineral, which in its occurrence, form, and chemical composition is quite similar to rhodusite, *viz.*: Heddle's abriachanite, a blue fibrous substance found in the clefts of the Old Red conglomerates, underlying schists, granite, etc., from Abriachan (Scotland), etc. Dana and others have considered abriachanite as related to crocidolite, but that is not the case. Abriachanite, like rhodusite, is an iron amphibole very poor in lime, rich in magnesia (like glaucophane), while crocidolite is an iron amphibole very poor in lime and also in magnesia (like riebeckite, as Lacroix has stated).

One analysis of abriachanite (XV) poor in soda (Hintze p. 1268) seems to represent the Fe'''— glaucophane corresponding to the gastaldite formula. But, as we have no other details about the properties of abriachanite regarding its similarity with rhodusite, and as rhodusite is better known, I propose to identify abriachanite with rhodusite, and to retain the name *rhodusite* for the end member (rich in Fe) of the glaucophane series.

Crocidolite (?).—I had the opportunity of studying some blue amphiboles like crocidolite, in some syenites which show exactly the same mineralogical composition and phenomena as have been described by Chestner, W. Cross, A. C. Lane, and others, in many such rocks. The occurrence, the form, and the rather obscure properties make the determination of these minerals very difficult and their identification with other minerals (crocidolite, rhodusite, etc.) almost impossible. As the properties of crocidolite are insufficiently known (pleochroism and absorption like riebeckite and crossite-rhodusite, $\mathfrak{a}:c = 10°–21°$, optic character positive), an identification of the mineral without analysis is valueless.

The constitution of crocidolite is:

$$\begin{array}{rl} N_2SiO_3 & \\ 3(FeMg)SiO_3 & \\ Fe_2Si_3O_9 & \quad Fe'':Mg = 4:1 \text{ minimum.} \\ \pm\, H_2SiO_3 & \end{array}$$

i.e., the formula of a rhodusite where almost all Mg is replaced by Fe″; except for water, it is the identical constitution of the riebeckites of Colorado and of Cape Ann, Massachusetts.

The blue asbestos-like amphibole in the syenite of Spanish Peak, Plumas County, California, is identical (optically) with the blue amphibole from Rosita Hill described by Cross. Pleochroism: $\mathfrak{a}$ = Prussian blue, $\mathfrak{b}$ = lighter blue, $\mathfrak{c}$ = greenish blue. Absorption very strong: $\mathfrak{a} > \mathfrak{b} > \mathfrak{c}$; the colors are very intense. Angle of extinction (in the opposite side of that of katophorite) $\mathfrak{a}:c = +21°$ ($\mathfrak{c}:c = -69°$). The axial plane seems to be longitudinal; on account of the absorption and dispersion ($\rho < v$) one cannot determine the optic character. $\gamma - \beta$ very small, almost zero; $\beta - \alpha = 0.004$ ca.

It is very important to note that some sections from this syenite and some from Rosita Hill (a section in the collection of Dr. Palache) show such orientation on (001) and (010) that we can suppose the axial plane to be perpendicular to the plane of symmetry: $\mathfrak{a}:c$, $\mathfrak{c} = b$. This fact indicates that crocidolite undergoes the same variation in its properties as glaucophane, and in the same way.*

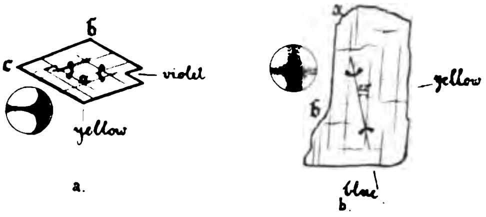

Fig. 2.—Crocidolite (Cross' amphibole) with axial plane normal to the plane of symmetry. **a**, basal section, **b**, clinopinacodal section.

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* In Vienna I discussed the chief points of this paper with Professor F. Becke, and Dr. C. Hlawatsch. The latter showed me an arfvedsonite-like amphibole with transverse axial plane ($\mathfrak{a}:c$; $\mathfrak{c}$ b), which he was studying. In the same rock there occur arfvedsonite and ossanite (n.s. Hlawatsch), like the crocidolite from Rosita Hill and Spanish Peak, with transverse axial plane.

These amphiboles are optically related to crocidolite; the crocidolite is related, optically and chemically, to arfvedsonite and riebeckite on one side, to rhodusite, and to glaucophane on the other side.

Another similar blue fibrous amphibole in the quartz from Oak Ridge, California, is very probably crossite; the optical orientation ($\mathfrak{b}:c = -17°$) and pleochroism are identical with crossite.

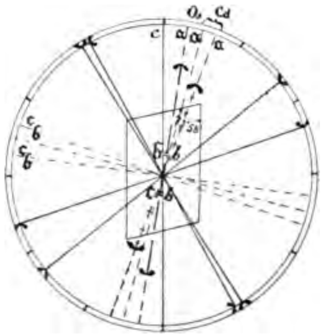

Fig. 3.—Stereographic projection on (010) of the optical orientation of common crocidolite, Cd., with normal axial and osannite, Os.

Relation between optical properties and chemical composition in the glaucophane series.—Comparing the analyses of the amphiboles from the glaucophane series (Table I), we see that Na_2O, FeO, and MgO undergo little or no variation, while Al_2O_3 and Fe_2O_3 show variation in opposite directions.

(*a*). The intensity of color and pleochroism (absorption) are not due only to the amount of Na_2O (or Na_2SiO_3), because the glaucophanes of Zermatt, Syra, San Pablo, etc., are very different in their absorption, and still have almost the same amount of Na_2O. Very probably the Na_2SiO_3 determines the shade of the color, but not the intensity.

A. Lacroix* has emphasized the fact that the glaucophanes rich in iron have more intense colors; Brogger† states too that amphiboles rich in iron (but without Ti) are blue. The accompanying analyses verify these statements in respect to Fe_2O_3. The amount of FeO, however, seems to have no influence on the

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* A. Lacroix, Mineralogie de la France, p. 700.

† W. C. Brogger, Eruptivgesteine des Kristiania Gebiet, I, 37.

TABLE OF ANALYSES.* I

		SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	H_2O	Analysers
I.	Gastaldite, St. Marcel,	97	21	—	12	—	10	4	10	—	14	*Cossa.*
II.	Gastaldite, Shikoku,	95	15	6	6	—	11	9	8	—	—	*Yoshida.*
III.	Glaucophane, Beaune,	94	14	—	13	1	20	4	13	—	—	*Colombo.*
IV.	Glaucophane, N. Caledonia,	88	14	—	14	—	27	7	8	1	7	*F. Liversidge.*
V.	Glaucophane, Syra,	94	12	—	16	—	20	4	15	—	—	*Schederman.*
VI.	Glaucophane, Val Gressony,	92	12	—	11	—	22	5	14	—	16	*Zambonini.*
VII.	Glaucophane, Syra,	92	15	2	10	—	20	4	15	—	—	*Luedecke.*
VIII.	Glaucophane, Zermatt,	96	12	1	8(0)	—	32	4	12	—	(14)	*Bodevig (Berwerth).*
IX.	Glaucophane, I. Groix,	94	12	2	6	—	30	4	13	1	—	*Schluttig.*
X.	Glaucophane, Syra,	96	11	2	14	—	24	2	11	—	—	*Washington.*
XI.	Glaucophane, San Pablo, Cal.,	88	11	2	13	—	28	5	10	—	14	*Blasdale.*
XII.	Uniaxial glaucophane, San San Pablo, Cal.,	90	9	3	14	1	25	3	13	—	10	*Blasdale.*
XIII.	Crossite, N. Berkeley,	92	5	6	13	—	23	4	12	—	—	*Tangier Smith.*
XIV.	Rhodusite, Rhodos,	92	—	10	10	—	28	2	10	1	11	*Foullon.*
XV.	Abriachanite,	91	3	19	5	1	32	5	2	—	8	*Jolly.*
XVI.	Abriachanite,	85	—	9	14	—	27	2	10	1	26	*Heddle.*
XVII.	Abriachanite,	87	—	6	21	—	26	2	11	1	16(+38)	
XVIII.	Crocidolite, Orange River,	87		13	23	—	5	1	9	—	20	*Chestner and Cairns.*
XIX.	Crocidolite,	87	1	13	23	—	4	—	10	—	9	*Doelter.*
XX.	Crocidolite,	85	—	11	29	—	—	—	11	—	20	*Chestner and Cairns.*
XXI.	Hornblende, Miask,	98	12	9	7	4	11	1	7	—	—	*Johnsen.*

*For making more obvious the chemical constitution of the amphiboles, I give here the analyses calculated in molecular proportions (to two figures only) of the constituent oxides, obtained from the percentage quantities divided by the respective molecular weights of the oxides.

color of absorption, all glaucamphiboles having almost equal FeO. Grunerite ($FeSiO_3$) and the amphiboles related to it are very faintly colored, with almost imperceptible pleochroism, and it is known that by heating glaucophane Oebbeke[*] has obtained a variation of the pleochroism on $\mathfrak{c}$ = reddish brown, on $\mathfrak{b}$ and $\mathfrak{a}$ = yellowish green to colorless, explained as due to the oxidation of FeO to Fe_2O_3. Inspection of the analyses shows clearly the influence of Fe_2O_3 on the absorption of these minerals; gastaldite and glaucophane very faintly colored, glaucophane uniaxial, in general strongly colored, crossite and rhodusite very intensely colored and with strong absorption. I may further add that the other series of blue amphiboles with extremely strong absorption, osannite, arfvedsonite, riebeckite, crocidolite, etc., are the amphiboles richest in Fe_2O_3; then philipstadite and others (with only 1 or 2 per cent. Na_2O but rich in Fe_2O_3) show a strong absorption and pleochroism in blue.

(*b*). Lacroix has stated also that the angle of extinction is smaller in the normal glaucophanes than in those passing over into common hornblende or actinolite. Many of our slides which show glaucophanes and karinthine or actinolite as forming one single prism verify this suggestion.

Further, I have remarked in the glaucophane series that with the increase of intensity of color, an increase in the value of the angle of extinction occurs, $\mathfrak{c}:c$ (glaucophane) or $\mathfrak{b}:c$ (crossite). A comparison of the whole group of Al Fe‴ amphiboles has convinced me that in general the size of the angle of extinction $\mathfrak{c}:c$ (or $\mathfrak{b}:c$) is related neither to the amount of Al_2O_3 (as Wiik has emphasized), nor to the amount of Fe_2O_3, but to the proportion of their molecular coefficients of combination in the amphibole constitution.[†] In this way we can explain why the different members of the glaucophanes, riebeckites, barkevikites, common hornblendes (soretite, karinthine, etc.), and basaltic hornblendes are minerals in general of constant formula, but are very different in their optic orientation; *e.g.*, in the glaucophane series:

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[*] Oebbeke, Zeits, für Kryst, 1887, 12, 286.

[†] Brögger was the first to state that the angle $\mathfrak{c}:c$ increases with the amount of iron and alkali. Blasdale says, *loc. cit.*, in respect to glaucophane "there is perhaps a connection between the position of the acute bisectrix and the relative amount of ferric and aluminum oxide."

	$Fe_2O_3:Al_2O_3$	$\mathfrak{c}:c$ or $\mathfrak{b}.c$
Gastaldite and Glaucophane	0—1/4	0— 6° (rarely larger)
Gastaldite of Skikoku	2/5	—11°
Mn Gastaldite of Miask	3/4	(+?)36°
Glaucophane uniaxial	1/2	—10° to —13°
Crossite	1/1—3/2	—16° to —20°
Rhodusite	>10/2	?(4°)
In other series:		
Crocidolite	>10/1	>70°
Riebeckite, Osannite	>10/1	>75°
Amph. of Kårböle	2/1	—15°
Barkevikite	<2/3	—14°
Barkevikite	2/3	—20°
Hudsonite	<1/2	— 9°
Hastingsite	2/3	—25°
Soretite	3/5	—17°
Basaltic hornblende	<1/2	0 to —12°
Kärsulite	<1/2	—10°
Kataphorite (Sao Miguel)	3/2	—23°
Etc., etc.		

So far as I know, only some arfvedsonites and common hornblendes (karinthine, pargasite, etc.) seem not to follow this rule, but there is an explanation for this, as the corresponding series is not well known. Very probably a large quantity of FeO together with Fe_2O_3 affects the increase of the angle of extinction in greater measure than Fe_2O_3 only: *e.g.*, in the case of crocidolite, arfvedsonite, riebeckite, etc.

(*c*). An interesting, perhaps the most obvious, influence of the amount of Fe_2O_3 on the optic properties is the variation of the birefringence, $\gamma - \beta$. Dr. A. C. Lane, as well as many other petrologists, has remarked that the green amphiboles in some alkali rocks become bluish at the periphery, and the birefringence decreases. He explains this as an influence of the feldspars on the amphiboles, and has given an empirical formula which connects the amount of Na with the birefringence ring:

$$Na = \frac{90}{17}(0.012 - b),$$

where Na = soda content of the amphibole, and b = the birefringence of the orthopinacoid section which is to be taken positive or negative according as the vertical axis is $\mathfrak{c}$ or $\mathfrak{a}$ (resp. $\mathfrak{b}$)

Table I shows us that this formula is not general, because the glaucophane from Zermatt, etc., and the uniaxial glaucophane from San Pablo, have almost equal Na_2O, but are very different in their $\gamma - \beta$. Nevertheless, the ideas of Lane served as a starting point for the following discussion.

The statement of Tschermak (Min. Mith., 1871, 38, 40), that with the increase of Fe in the aluminous amphiboles the optic angle increases around 𝔠 and decreases around 𝔞 (usually the first bisectrix), is well known. If we consider the Fe''' (better $Fe_2Si_3O_9$), this statement is quite true, not only in the glaucophane series but in general in the FeAl amphiboles with metasilicate formula. Of course, when 2 V becomes smaller around a negative bisectrix, $\gamma - \beta$ also becomes smaller, and finally attains the value zero when the amphibole becomes uniaxial. But the rule is still more general; the variation of γ and β can proceed in such a manner that $\gamma - \beta$ passing through zero then becomes negative, *i.e.*, β takes the place of the former γ, and *vice versa*. In this case we have an amphibole with transverse axial plane, and have established a continuous variation from the common amphibole with parallel axial plane, through the uniaxial amphibole to the amphibole with transverse axial plane.

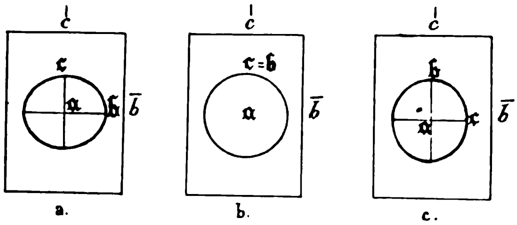

Fig. 4.—Ellipsoid of elasticity, section parallel to *c* and *b* , of glaucophane, **a**, uniaxial glaucophane, **b**, and crossite, **c**.

We have seen this whole series with all possible intermediate members in the glaucophane group, and it is easy to see that it is a function of $Fe_2Si_3O_9$. The more Fe_2SiO_3 replaces Al_2SiO_3, the more the axial angle and $\gamma - \beta$ decrease: for Fe''' : Al = 1 :3 corresponds to the uniaxial glaucophane ($\gamma = \beta$), while for Fe : Al = 6 :5 we meet with a crossite with transverse axial plane and 2 V almost 90°. Perhaps rhodusite, which is the Fe''' glaucophane, is a crossite of positive optic character, or even a uniaxial positive glaucophane, with the optic axis perpendicular to the plane of symmetry. The whole phenomenon can be clearly indicated in a diagram: In a system of coördinates, let the ordinates represent the indices of refraction, and the abscissae represent the amount of Fe_2O_3 causing the variation of the former. Accordingly we have Fig. 5, which shows that we can have the following glaucamphiboles:

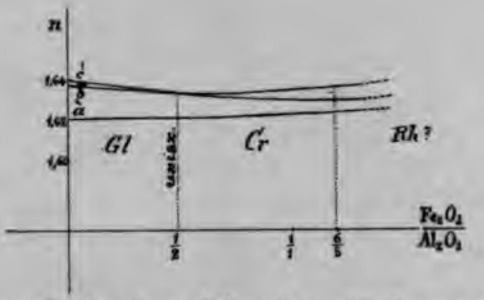

Fig. 5.—Diagram showing the variation of $\gamma - \beta$ and $\gamma - \alpha$ with the ratio of Fe_2O_3: Al_2O_3; Gl = glaucophane; Cr = crossite; Rh? = rhodusite.

	Coefficient of Al_2O_3	Coefficient of Fe_2O_3	Position of axial plane	c:c (or b:c)	2V	Optic character	Formula*
Gastaldite	21—15	0— 6	∥(010)	0— 6°	40°—60°	—	2 G + M'; (6/4G + 2/4R + M)
Glaucophane	14— 9	0 — 3	∥(010)	0— 6°	30°—50°	—	G + M; (3/4G + 1/4R + M)
Glaucophane uniaxial	8	4	......	10°	0°	—	2/3G + 1/3R + M
Crossite	6	6	⊥(010)	15°	50°	—	1/2G + 1/2R + M
Crossite	4	7	⊥(010)	20°—30°	90°	—	1/3G + 2/3R + M
Rhodusite	0— 2	12—10	⊥(010)	(40°)	(50°—30°)	(+)	R + M, (1/5G + 4/5R + M)
Abriachanite	0— 3	21—18	(?)	(?)	(?)	(?)	2R + M

We shall see further on that just the same optic variation takes place in the karinthine series and in the riebeckite (crocidolite) series. As regards karinthine, we shall discuss it later on, but we may dwell on crocidolite and riebeckite a little in this place.

I do not know the constitution of Cross's crocidolite, and still less that of the crocidolite with transversal axial plane, but I

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* In these formulae $G = Al_2Si_3O_9$; $R = Fe_2Si_3O_9$; M, (or M'): the sum of the other metasilicates $= Na_2SiO_3 + FeSiO_3 + 2$ (or 1) $MgSiO_3$ ($+ H_2SiO_3$).

TABLE OF ANALYSES. II.

		SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	H_2O	Analyser.
I.	Arfvedsonite, Greenl.	80	—	1	1	49	—	—	5	11	3	11	*F. Berwerth.*
II.	Arfvedsonite, Greenl.	73	—	4	2	46	1	1	8	13	1	—	*Lorenzen.*
III.	Arfvedsonite, Sardinia	82	—	5	3	39	1	—	—	17	2	—	*Bertolio.*
IV.	Riebeckite, Colorado	83	2	—	9	26	2	1	—	13	2	—	*Koenig.*
V.	Riebeckite, Cape Ann	83	—	1	11	27	—	—	6	12	—	9	*Gregory.*
VI.	Riebeckite, Jacobdeal	76[1]	—	7[2]	9	26	4	4	8	7	1	3	*Mrazec.*
VII.	Riebeckite, Sokotra	83	—	—	18	14	1	1	2	14	1	—	*Sauer.*
VIII.	Riebeckite, Jacobdeal	83	—	—	18	9	4	2	2	9	1	—	
IX.	Arfvedonite (?) Christinia	83	—	2	21	—	—	1	—	20	—	—	*Rördam.*
X.	Osannite	81	—	1	10	28	2	—	2	10	1	10	*Dittrich.*
XI.	Hornblende, Sao Miguel	81	—	6	—	42	—	9	7	7	2	—	*Reiss.*
XII.	Kataphorite, Sao Miguel	76	—	4	6	37	4	6	9	10	1	—	*Osann.*
XIII.	Barkevikite, (?) Brevig	77	2	3	—	35	3	14	10	12	3	—	*Plantamour.*
XIV.	Hornblende Hoechenkröchen	75	—	9	5	31	7	7	1[1]	7	3	—	*Föhr.*

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[1] Obtained by difference. [2] $+ZrO_2$. The mineral incloses some zircon, haematite, and aegirite.

believe that they must be very rich in Fe_2O_3. As a rule, all analyses of crocidolite show a large amount of Fe_2O_3 (16 to 20 per cent.); unfortunately we lack optical determinations of these, and no analysis has been made of Lacroix's positive crocidolite (axial plane parallel to (010)). Fortunately the question in the riebeckite series is quite clear. There are many riebeckites known; some poor in Fe_2O_3 but very rich in FeO, the end member being arfvedsonite; some others very rich in Fe_2O_3 but poor in FeO, including in the latter osannite, the new amphibole of Hlawatsch. (See the analyses in Table II.)

The variation within wide limits of the optic constants of those arfvedsonites which have been studied, as well as of the riebeckites, is well known; nevertheless we see a great difference in their chemical constitution. We can, however, in general state that the analyses of some arfvedsonites (of San Piedro III, Sao Miguel XI, Hochenkröchen XIV), and of some riebeckites (Colorado, Cape Ann) give a formula of the type of glaucophane (crossite or rhodusite) where Mg is replaced almost entirely by Fe (and Mn) and Ca by Na_2.

In the hope of bringing some order into this interesting group of amphiboles, I propose the following classification:

	Fe_2O_3	a : c	Axial plane	2 V	Optic character	Formula
Arfvedsonite	very poor	$-70°-80°$	‖(010)	very large	—	From $5FeSiO_3 . Na_2SiO_3 . (H_2SiO_3)$ to $4\text{-}5\,FeSiO_3\ 1\text{-}2\,Na_2SiO_3 \cdot FeAlSi_3O_9$
Riebeckite (Colorado)	rich	ca $-85°$	‖(010)	small	—	From $3FeSiO_3 . 2Na_2SiO_3 . Fe_2Si_3O_9$ to $2FeSiO_3 . Na_2SiO_3 . 2Fe_2Si_3O_9\ H_2SiO_3$
Osannite*	rich	ca -80	⊥(010)	very large	—	

(*d*). Both the literature and my own observations show that the dispersion of the optic axes and bisectrices stands in close relation to the intensity of the blue color and to the intensity of the absorption. As the latter are a function of $Fe_2Si_3O_9$, as has been stated above, the dispersion must also be a function of $Fe_2Si_3O_9$. I believe that the above is sufficient to demonstrate the influence of $Fe_2Si_3O_9$ on the optic properties in general in the AlFe amphiboles of metasilicate type.

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* I owe the information about the optical properties and the chemical composition of osannite to the courtesy of Dr. C. Hlawatch.

KARINTHINE AMPHIBOLES; COMMON HORNBLENDES.

Karinthine, pargasite.—Karinthine is the name given by Werner to the dark hornblende from the eclogites of Sanalpe in Kärnten or Carinthia (Hintze, p. 1201). Many mineralogists (Tschermak, Naumann, Lacroix, Dana, Rosenbusch, and others have included this material among the common hornblendes. E. Weinschenk, in *Gesteinsbildende Mineralien,* has brought it to notice as a member intermediate between the common green hornblende and blue glaucophane or gastaldite. I use the name in the same sense for bluish green or blue-black amphiboles which under the microscope show a bluish green color parallel to the length of the prism. I believe that Barrois was the first to identify this amphibole from the glaucophane schists with karinthine. The Californian bluish green karinthine is identical with the Alpine karinthine (Val d'Aosta, Zermatt, and elsewhere) which I was able to examine (slides in the possession of Dr. C. Palache), and with those from Val Canaria, Val Pioia, Mt. Taunus, etc. (Rosenbusch). It is certain that this kind of hornblende has sometimes been described as glaucophane, and perhaps the determinations of glaucophane with $\mathfrak{c}$ = ultramarine or bluish brown, $\mathfrak{b}$ = bluish green or lavender blue, and with a large angle of extinction, refer to karinthine, which occurs in almost all glaucophane schists. Lacroix[*] has distinguished betwen these amphiboles and glaucophane; they are namely "glaucophane passant à la hornblende," or members "intermediaires entre la glaucophane normale et les amphiboles dépourvues d'alcalis." Rosenbusch,[†] who states that between glaucophane, or rather gastaldite, and common hornblende or actinolite there is a series of intermediate forms, suggests that Weidmann's hudsonite may be such an intermediate form (see Table III). I may add that the chemical composition of hudsonite hardly differs from that of hastingsite and of barkevikite, especially of Montana, Beverley, etc., which minerals together with noralite seem to be both chemically and optically members intermediate between common hornblendite (soretite) and arfvedsonite.[‡] (See Tables II and III.)

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[*] A. Lacroix, Mineralogie de la France, 1903.

[†] H. Rosenbusch, Microscopische Physiographie, I. 2, 1905, p. 240.

[‡] The glaucophanes (or glaucophane-like amphiboles) described by Szadecky, Washington, etc., as occurring in many igneous rocks enter perhaps into the same category of amphiboles.

From the chemical point of view we find karinthine (and pargasite) as a form intermediate between gastaldite on the one hand, and common hornblende (edenite or soretite) on the other hand. (Table III.) Karinthine and pargasite are more or less similar in their metallic constituents, but pargasite contains an appreciable quantity of fluorine, which replaces silica (in an equal coefficient, $= 10$). This chemical difference, together with the positive optic character of the amphiboles of Pargas, justifies us in distinguishing between pargasite and karinthine. Besides, pargasite is quite different from karinthine both in its genesis and in its occurrence, which is another argument for the identification of the bluish amphibole from the glaucophane schists with karinthine. On the Californian karinthine (?) I have made the following determinations: Pleochroism: $\mathfrak{c} =$ greenish blue to bluish green, $\mathfrak{b} =$ olive green, $\mathfrak{a} =$ pale yellow to greenish yellow. Absorption $\mathfrak{c} < \mathfrak{b} > \mathfrak{a}$. Angle of extinction variable, $\mathfrak{c}:c = 17–22$, in obtuse angle β. The angle measured on cleavage lamellae is hardly different from the maximum angle measured in slides and on (010). The axial plane is parallel to (010). 2 E very large, optic character negative. $\gamma - \beta =$ ca. 0.022. Small dispersion, $\rho < v$.

In some schists from California (and also in some from the Alps) I have found a dark green or black hornblende with:

Pleochroism:
$\mathfrak{c} =$ greenish blue to light ultramarine,
$\mathfrak{b} =$ olive green to dirty green,
$\mathfrak{a} =$ honey-yellow to greenish yellow.

Angle of extinction in general larger than in the former karinthine, $\mathfrak{c}:c = 20°–28°$. Other properties almost the same. In one section only (II, 6). I found also a *positive* hornblende associated with glaucophane: $\mathfrak{c} = \mathfrak{b} =$ greenish, $\mathfrak{a} =$ colorless, $\mathfrak{c}:c = -48°$; 2 V very small, axial plane (010). Unfortunately we possess no analysis of the Californian karinthine to see whether the conclusions stated for glaucamphiboles hold in the karinthine series. I may remark, however, that some Al (and Fe''') in the existing analyses belongs to a syntagmatite formula (orthosilicate), as in the syntagmatite of Jan Mayen, philipstadite, soretite, etc. Karinthine is almost Fe''' — free; philipstadite, hudsonite, and other such amphiboles contain some Fe''' which replaces Al. Perhaps the darker varieties correspond, as in the glaucamphiboles, to those richer in Fe'''. I have found karinthine-like amphiboles in many rocks, generally alkali rocks, other than schists, an occurrence which is also put on record in the literature of the subject. As I possess no analyses, the identification with karinthine or soretite is doubtful.

In fact, if we consider the analyses of pargasite, karinthine, soretite, philipstadite, hudsonite, hastingsite, noralite, etc., we notice that while alkali, CaO, and the sum of Al_2O_3 and Fe_2O_3 remain almost constant, FeO and MgO vary in opposite directions; karinthine has 7 FeO : 43 MgO, noralite 40 FeO : 5 MgO, and the others have intermediate proportions. As far as the literature is known to me, I do not know of a continuous variation in optical properties which could be explained by this variation of chemical composition, and I may state again that the amount of iron as FeO (not Fe_2O_3) has no influence upon the physical properties of the amphiboles. This does not hold for Fe_2O_3. The sum of the coefficients of Al_2O_3 and Fe_2O_3 in the above named series is almost constant, = 14 (the extremes being 12 and 18, karinthine and noralite being almost free from Fe''', while the analyses of the other members give more or less Fe''' in the proportion of ⅖ to ½). I have tried to prove above that the size of the angle of extinction in this series also is a function of this proportion.

Further, in the case of karinthine we have seen, and in the case of barkevikite, philipstadite,* hudsonite, hastingsite, etc., the literature supports the suggestion, that the angle of extinction is proportional to the intensity of color and absorption; the phenomenon is quite clear if these amphiboles show a zonary structure, as frequently happens.

Unfortunately we have not always good and complete determinations of the optical properties corresponding to the analyzed individuals, and accordingly we cannot, in general, verify the dependence of the angle of extinction and the intensity of absorption on the proportion Fe_2O_3 : Al_2O_3, but the few precise data (philipstadite, hudsonite, hastingsite, barkevikite, etc.) which we have seem to show that the rule is quite general.

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* R. Daly, On a New Variety of Hornblende, Proc. American Academy of Arts and Science, XXXIV. 16, 1899.

If this suggestion holds, then the making of new species in a type because the pleochroism and angle of extinction differ more or less, is worse than unnecessary, for we have seen clearly in the glaucamphiboles that the replacing of Al_2O_3 by a small quantity of Fe_2O_3 brings about a noticeable variation in these two properties and also in the etch-figures. There would be an unlimited number of species in any series.

In order to make the nomenclature more simple and natural, I should like to propose the following classification:

	Al_2O_3	Fe_2O_3	$\mathfrak{c}:c$	Plane of axes	2 V	Optic character	Formula[*1]
Pargasite	14—11	0—3	—25°	(010)	50°—60°	+	S+0 to 1G+4 to 3K (+Fe)
Karinthine	14—12	0—2	—17° to —28°	(010)	very large	—	S+0 to 1G+4 to 3K
Soretite[*2]	10	6	—17° to (—28°)	(010)	80°—90°	—	S+1 to 2G+3 to 2K
Barkevikite[*3]	16—10	0—4	—12° to (—25°)	(010)	±large	—	S+3G+K
Noralite[*4]	12	?	?		?	—	S+3 to 4G+1 to 0K

[*1] Where: S = Syntagmatite molecule, = $(AlFe_2)\ (CaNa_2)_2\ Si_3O_{12}$, G = grunerite mol., = $FeSiO_3$; K = kupferite mol., = $MgSiO_3$.

[*2] Under soretite are to be included the hornblendes corresponding to the analyses XI, XII, XIII, XCI, CXXIII, CXXIV, CXCVIII, CCXL, etc., in Hintze's Manual; further, philipstadite (also CXXVI, CXLVIII, CXLVI, etc.) and camsigradite which is a Mn-containing philipstadite. See for details, Hintze, Handbuch der Mineralogie, II.

[*3] Under barkevikite could be included the hornblendes corresponding to the analyses CCL, CCLII (see Table II, No. XI and XII), etc., in Hintze's book. Also hudsonite and hastingsite, (Tab. III), although they have very pronounced pleochroism in blue; I may remark that the brown barkevikites are not only titaniferous but are also very poor in Fe_2O_3.

[*4] Under noralite (Dana) must be included also the hornblendes corresponding to CCXLVI, CCLII, etc., in Hintze's book. See V and III in Tab. III.)

Perhaps to karinthine, soretite, or barkevikite corresponds a series from aluminous to ferruginous amphiboles parallel to that of glaucophane rhodusite, these known members being the most aluminous.* As we can see in the accompany table (for details see Hintze's manual, Rosenbusch's, etc.), analyses of karinthine amphiboles rich in Fe''' are quite unknown. Very probably it is to this unknown catgeory of karinthines that the green or bluish

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[*] I may remark that in the riebeckite series the members rich in Fe''' are almost the only ones known; that of Jacobdeal analysed by L. Mrazek (Table II., No. VI) has 7% Al_2O_3 (+ZrO_2, etc.)

TABLE OF ANALYSES. III.

		SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	H_2O	Analysers
I.	Karinthine, San Alpe	82	(+1Fl)	12	1	7	—	43	19	4	1	6	*Rammelsberg.*
II.	Pargasite, Pargas	70	(+10Fl)	11–16	3–0	14–2	—	33–49	27–21	5–2	3–4	—	
III.	Hornblende, Teneriffa	77	—	9	—	41	—	12	17	—	—	—	*St. Cl. Deville.*
IV.	Noralite, Nora	70	—	12	—	40	—	5	20	—	—	4	*Klaproth.*
V.	Hornblende, Kikertars	74	—	2	3	40	3	7	22	1	2	7	*Janovsky.*
VI.	Barkevikite, Greenl.	70	1	6	4	30	2	9	18	5	3	1	*Rammelsberg.*
VII.	Barkevikite, Greenl.	71	—	11	4	27	1	3	19	9	2	—	*Flink.*
VIII.	Barkevikite, Montana	64	2	16	2	30	—	6	19	5	2	—	*Lind.& Melv.*
IX.	Hudsonite	61	1	12	5	33	1	2	19	5	2	—	*Weidmann.*
X.	Hornblende, Beverley	59	2	9	6	34	2	—	12	8	5	17	*Wright.*
XI.	Hastingsite	57	2	11	8	30	1	3	18	5	2	3	*Adams & Harin.*
XII.	Bergamanskite	61	—	15	9	32	—	2	9	7	—	2	*Lucchetti.*
XIII.	Philipstadite	63	—	12	3	17	1	30	24	1	3	—	*Rammelsberg.*
XIV.	Philipstadite	75	—	7	5	24	—	21	22	1	—	4	*Daly.*
XV.	Camsigradite	77	—	13	—	18	9	20	16	5	1	—	*Müller.*
XVI.	Soretite (mean)	67	2	10	6	14	—	30	22	4	1	3	*Duparc & Pearce*
XVII.	Hornblende, Jan Mayen	65	—	14	8	8	—	26	20	4	3	2	*Scharizer.*
XVIII.	Kaersutite	67	7	14	6	5	—	35	22	4	2	—	*Lorenzen.*
XIX.	Basaltic Hornblende (mean)	67	3	15	7	5	—	35	20	4	2	—	

green amphiboles, uniaxial or with transverse axial plane, belong; these amphiboles are described in the literature, and I was fortunate enough to find some in the rocks studied.

If the relation between Fe_2O_3 and optic properties exists also in the karinthine group (as I have tried to prove above) as in the glaucamphiboles, then the following amphiboles with transverse axial plane must be very rich in Fe_2O_3.

Laneite (*n. v.*).—As far as I know, Dr. A. C. Lane was the first to make known (in 1895, in a letter to Dr. C. Palache) an amphibole with transverse axial plane in a theralite from Michigan; at the same time he suggested that there might be an amphibole which was uniaxial, or even for a definite composition isotropic; he connected this phenomenon with the amount of Na. Some hornblendes with very weak birefringence (nearly isotropic) have been described by Milch,[*] and hastingsite with Al_2O_3: $Fe_2O_3 = 11:8$; $\mathfrak{c}:c = 25°–30°$; $2E = 30°–45°$, optic character negative, $\mathfrak{a}$ = yellowish green; $\mathfrak{b} = \mathfrak{c}$ = deep blue-green, by F. D. Adams and J. Harrington.[†] Such blue-green hornblendes with very small optical angle have been often mentioned as occurring in the alkali rocks. Dr. C. Hlawatsch[‡] has described a uniaxial amphibole as occurring in the gabbro-diorite from Jablanica (Bosnia) $\mathfrak{a}$ = deep yellowish brown, $\mathfrak{b} = \mathfrak{c}$ = deep blue-green; $\mathfrak{c}:c = 18°$, $2\ V = 40°–0°$ (in the blue hornblende, in the brown one very large). He considers it as intermediate between the common hornblende (with the axial plane parallel to 010) and the hornblende with transverse axial plane which he himself has found in the eleolite syenite porphyry from Viezzena Thal (Predazzo): $\mathfrak{a}$ = light yellow, $\mathfrak{b}$ = dark blue-green, $\mathfrak{c}$ = dark brown-green, $\mathfrak{b}:c = 25°$; $2\ V = 45°$; optic character negative.

It is a pity that these hornblendes, as well as the following, have not been analyzed; very probably they belong to the soretite or barkevikite type, and are very rich in Fe_2O_3. Optically, except for the position of the axial plane, they are similar to the hornblende of Wright[*] found at Beverley.

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[*] Milch, Die Schiefer des Taunus, Zeitschr. d. D. Geol. Gesellsch., XLI, pp. 394 and 423.

[†] Fr. D. Adams and B. J. Harrington, Amer. Jour. Sci., I. 1896, p. 210. Also in Rosenbusch.

[‡] C. Hlawatsch, Tscherm. Mittheil., 1903, p. 499, 4. *Ibidem*, XX, p. 43.

In the course of an investigation of riebeckite rocks and their inclusions (from Quincy, Massachusetts, Jacobdeal, Dabrogea, etc.) I was fortunate enough to find this kind of amphibole, which in my notes I have called *Lane's amphibole.* It is a dark colored amphibole (like barkevikite), with a very strong pleochroism: $\mathfrak{a}$ = brownish yellow, $\mathfrak{b}$ = green or brownish green, $\mathfrak{c}$ = bluish green or greenish blue; $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. Angle of extinction $\mathfrak{c}:c = 13°$ in the darker colored, up to 20° and even 26° (in this case $\mathfrak{b}:c$). The birefringence $\gamma - \alpha$ is large enough to be noticed, but $\gamma - \beta$ is very small, almost zero. 2 V of course very small or zero; very strong dispersion; $\rho < v$: optic character negative. In the darker colored lamellae with an excessive dispersion ($\mathfrak{b}\rho:c < \mathfrak{b}_v:c$), we meet with a transverse axial plane, 2 V very small around the same negative bisectrix.

Besides the inclusions of riebeckite granite, I have observed this mineral in a section (No. 304, the property of Dr. C. Palache) of glaucophane schist from Riffel Alp (Zermatt). In this section we have in some lamellae the blue-green amphibole with the axial plane parallel to (010); in others it is transverse to the plane of symmetry; angle of extinction $\mathfrak{c}$ (or $\mathfrak{b}$) : $c = 18°–20°$; optic character negative.[†] All these amphiboles are optically similar; there is also another which differs only in the angle of extinction.

In Rosenbusch's new manual we find a communication by W. Freudenberg about an amphibole from the shonkinite of Katzenbuckel: black (transparent brown or greenish), "very rich in iron." Pleochroism: $\mathfrak{a}$ = straw color, $\mathfrak{b}$ (or $\mathfrak{c}$) = deep red-brown, $\mathfrak{c}$ (or $\mathfrak{b}$) = green to yellow-green. Angle of extinction: $\mathfrak{c}$ (or $\mathfrak{b}$) : c variable up to 65° (?); $\mathfrak{b}\rho:c < \mathfrak{b}_v:c$; 2 V very small around a negative bisectrix. Axial plane in the central lamellae parallel to (010), in the periphal zones perpendicular to (010).

These observations all show that crossite-like amphiboles occur in the group of common hornblende, and are very probably Fe'''—amphiboles corresponding to the karinthine, barkevikite, or soretite formula. Until more detailed knowledge about this kind of amphibole is published, I propose to retain for such the name *laneite*, in honor of Dr. A. C. Lane, who has introduced new ideas and made new observations in this group of minerals.

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[*] F. E. Wright, Alkali syenit von Beverley, Tscherm. Mittheil, XX p. 310. See Table II. No. X.

[†] This amphibole must occur very frequently; for example, I believe that I recognized it in a slide of riebeckite granite from Socotra, although I studied the slide, the property of Professor A. Pelikan, No. 41, for a few minutes only.

Actinolite and an Actinolite with Transverse Axial Plane.—As a type of the actinolite from the rocks with glaucophane, we may take the actinolite of North Berkeley and San Pablo studied and analyzed by Blasdale (*loc. cit.*). It is very similar in its physical properties to the actinolite described by C. Palache as occurring in crossite schists, etc. Color, bluish green; pleochroism: $\mathfrak{c}$ = bluish green, $\mathfrak{b}$ = yellowish green, $\mathfrak{a}$ = yellowish to colorless; absorption faint, $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. Angle of extinction $\mathfrak{c}:c = 15°$; birefringence as usual; 2 E very large; the section (100) shows a negative bisectrix and one axis.

In one glaucophane schist (VIII 10) I found an interesting mineral which seems to be an actinolite with transverse axial plane. The relief is like zoisite. Pleochroism, $\mathfrak{c}$ = colorless, $\mathfrak{b}$ = green, more or less dark, $\mathfrak{a}$ = yellowish to colorless; angle of extinction, $\mathfrak{b}:c = -7°$ (measured on hemitropic lamellae which extinguish symmetrically). In the sections with parallel extinction the axial plane is transverse, with 2 E small around a positive bisectrix. Some lamellae show patches of glaucophane.

From the occurrence and optical properties of this mineral, it can be no other than an amphibole, *viz.*, an actinolite. I have met with it only in one rock (3 slides), and in so small a quantity that it was not possible to isolate it for further investigation.

I may here again remark that the position of the axial plane is near to the vertical, as in crocidolite and osannite, and not near to the horizontal, as in crossite and laneite.

II.

MATERIALS STUDIED.

GLAUCOPHANE SCHISTS.

On the Californian glaucophane schists there is an extensive literature, but in California, as in other countries, the problems are far from being solved. I add here some petrographic notes on some of these rocks merely as suggestions for future work, and especially as proofs in support of the theories advanced in the preceding section of this paper.

The numbers in these notes refer to the collection of slides of Professor J. P. Smith.

Eclogite.—Arroyo Hondo, Calaveras Valley. I. (4, 5.) Garnet in large crystals with inclusions of titanite, rutile, apatite, and karinthine, with patches of glaucophane. Ilmenite with edges of magnetite; hematite, golden yellow rutile sometimes included in titanite, epidote; lawsonite. Karinthine, with inclusions of zircon with halos of titanite rutile, etc., shows: $\mathfrak{c}$ = blue-green, $\mathfrak{b}$ = dark olive-green, $\mathfrak{a}$ = yellowish to colorless. Patches and edges of blue-violet glaucophane, max. ext. = -24°. 2 V large; the basal sections show an optic axis. Negative.

In another slide with much titanite, the karinthine with edges and patches of glaucophane gives a max. ext. -27° with stronger absorption (the colors much darker).

Another slide shows a karinthine: $\mathfrak{c}$ = blue green, $\mathfrak{b}$ = dirty olive-green, $\mathfrak{a}$ = yellowish green; ext. -28°; 2 V very large;* $\gamma - \alpha$ large; negative; axial plane = (010); a basal section shows an optic axis at the edges of the field of the microscope. Glaucophane shows: $\mathfrak{c}$ = azure blue to ultramarine blue, $\mathfrak{b}$ = violet, $\mathfrak{a}$ = bluish to colorless; 2 V large; negative; intergrown with karinthine.

Greenstone.—Calaveras Valley. I. 8, 8 (No. 10). Titanite, rutile, ilmenite, hematite, epidote, lawsonite (?), karinthine, chlorite, glaucophane intergrown with karinthine. Karinthine shows: $\mathfrak{c}$ = bluish green, $\mathfrak{b}$ = olive green, $\mathfrak{a}$ = yellow to colorless; absorption slight; ext. -20°; negative; basal sections show a second bisectrix and an optic axis. Glaucophane variable in pleochroism and absorption from pale colors to very dark ones; 2 V also variable from large to zero; negative.

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* Very large is over 60°; large is 60°—40°; small is less than 40°.

Greenstone (eclogite).—Calaveras Valley. I. 7. Well developed crystals of titanite; rutile with halos of leucoxene; karinthine, clinozoizite (colorless epidote) in large crystals, lawsonite, lotrite (?), quartz, chlorite with biotite and muscovite. Glaucophane occurs in lamellae with variable pleochroism and absorption, with remains of karinthine faintly colored like the glaucophane in general. As veins, or mixed with the other minerals in the rock, we find a yellowish mineral here and there with some greenish pigment; it occurs as lamellae and fibers with cleavage sometimes very well pronounced, often disposed in fans, forming sometimes a radial spherulite. The refractive index is 1.67; the occurrence and properties suggest lotrite. The lamellae with strong birefringence ($\gamma - \alpha$) extinguish symmetrically; some other lamellae give wavy extinction, and those with $\beta - \alpha$ very small show an angle of extinction of 15°. Relief and birefringence a little higher than in glaucophane. Pleochroism: $\mathfrak{a} = \mathfrak{c}$ = colorless; $\mathfrak{b}$ = greenish. The length of the lamellae is parallel to $\mathfrak{b}$; axial plane perpendicular to the cleavage; 2 V large down to very small around a positive bisectrix, even uniaxial. According to these properties this mineral is very similar to lotrite, from which it differs only slightly in the angle of extinction.[*] The lotrite (?) seems to be in genetic relation with the glaucophane and karinthine; some lamellae of glaucophane and karinthine pass into a mass of lotrite lamellae. The glaucophane, however, at the contact with the vein of lotrite (?) shows clearly a transformation into crossite. (Fig. 6.) It becomes very intensely colored (blue and violet), almost uniaxial, and the edges and lamellae which project into the interior of the vein have a much stronger pleochroism and absorption, and the optic orientation of crossite: $\mathfrak{c}$ = dark violet; $\mathfrak{b}$ = Prussian blue to indigo; $\mathfrak{a}$ = gray-violet; ext. –19°; birefringence very small; 2 V very large; dispersion very great. Karinthine shows an extinction of 19°.

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[*] For lotrite see: Granat-Vesuvianfels von Paringre by the author in Bulet. Soc. Sciinte., Bucharest 1901. Refer. Groth's Zeitschrift; Neues Jahrbuch, etc., and Rosenbusch.

glaucophane less (6°–10°), and crossite also 19° in the same direction as glaucophane and karinthine.

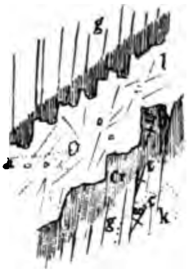

Fig. 6.—Glaucophane, **g**, with patches of karinthine, **k**, shows edges of crossite at the contact of a lotrite?, **l**, with actinolite, **a**, etc. ×30.

The transformation of glaucophane into crossite seems to be posterior to the genesis of glaucophane and karinthine, probably at the same time or even posterior to the filling up of the vein with lotrite (?), actinolite, and iron mica. It seems that at the time of the formation of the vein the glaucophane had suffered an impregnation with a foreign substance, or a transformation of FeO into Fe_2O_3, which had altered its chemical constitution and optical properties. It is to be remarked that in some other parts where glaucophane comes in contact with lotrite (?) one cannot observe a pronounced variation in the color or in the optical properties of the glaucophane.

Eclogite.—Oak Ridge, Calaveras Valley. I. 10. Garnet with rutile and ilmenite, the fissures filled with smaragdite (?), epidote, titanite with rutile; rutile with leucoxene, karinthine.

Eclogite.—Calaveras Valley. 1. Garnet with veins of chlorite. Lawsonite, much titanite, omphacite.

Glaucophane-gneiss.—Melitta, near Santa Rosa. II. 2, 3, 4. Quartz, titanite, garnet with the fissures filled with talc (?); much chlorite and margarite. Orthoclase, smaragdite. Karinthine with glaucophane very faintly colored; some patches of more intensely colored glaucophane show 2 V very small.

Another section of the same rock (II. 5) shows very large crystals of titanite; garnet; rutile with leucoxene. Karinthine shows: **𝔠** = greenish blue, **𝔟** = green, **𝔞** = yellowish; ext. = 20°; forms crystals with glaucophane showing: **𝔠** = ultramarine blue, $\mathfrak{b}$ = pale violet, $\mathfrak{a}$ = gray yellow. (Fig. 7.) Some lamellae of glaucophane with intense colors are almost *uniaxial.*

In another section (II. 6.) besides a glaucophane with $\mathfrak{c}$ = azure blue, $\mathfrak{b}$ = purple violet, $\mathfrak{a}$ = yellow to colorless, $\gamma - \beta = 0.002$, 2 V large, we find a greenish amphibole with patches of glaucophane. Pleochroism $\mathfrak{c} = \mathfrak{b}$ = greenish, $\mathfrak{a}$ = colorless. Birefringence weak; 2 V very small; positive; axial plane (010); ext. $(\mathfrak{c}:c) = -48°$.

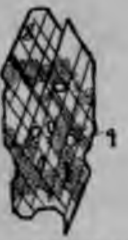

Fig. 7.—Glaucophane crystal, g, with patches of karinthine, k, quartz, q, ×30.

Quartzite.—San Luis Obispo. II. 12. Recrystallized quartz in some zones undisturbed, in others crushed. Garnet, titanite, spinel grown also in glaucophane. Glaucophane with variable colors, some lamellae rising up to those of the crossite. Angle of the optic axis varying inversely to the intensity of the color.

Gneiss.—Belmont School, Belmont. II. 17. Garnet, ilmenite with hematite, rutile with leucoxene, much musovite. Glaucophane in radical lamellae with very weak absorption; angle of extinction very small; 2 V large; negative.

Quartzite.—Oak Hill, San José. II. 20. Idioblastic quartz, garnet inclosed in glaucophane; rutile and titanite in beautiful crystals; muscovite (paragonite?), lawsonite. Glaucophane with intense colors; 2 V very small; in some ultramarine lamellae almost uniaxial. Muscovite with rutile inclosed in glaucophane.

Mica schist.—Calaveras Valley. II. 22. Brown garnet inclosed in glaucophane; little muscovite. Glaucophane with intense colors and strong absorption; $\mathfrak{c}$ = ultramarine blue, $\mathfrak{b}$ = purple violet, $\mathfrak{a}$ = yellowish green; ext. angle very small; $\gamma - \alpha = 0.021$; $\gamma - \beta = 0.005$ ca. 2 V very small, negative; axial plane (010).

Lawsonite gneiss. Three miles west of Redwood. III. 2, 7.

Ophitoblastic structure. Titanite, lawsonite, ilmenite, hematite, rutile with leucoxene. Glaucophane in large crystals: $\mathfrak{c} =$ Prussian blue, $\mathfrak{b} =$ purple violet, $\mathfrak{a} =$ gray; some lamellae are quite uniaxial. In sect. III. 7 the glaucophane has paler colors; 2 V small.

Lawsonite gneiss. Helmann ranch. III. 3, 14.

Ophitoblastic structure. Glaucophane in some lamellae very pale with 2 V very large; extinction angle very small. Titanite, lawsonite in glaucophane, but also glaucophane in the lawsonite crystals.

Epidote schist. Hooper Dairy, Schrader Tract, near Redwood. III. 11.

Epidote, lawsonite, pyrite, chlorite. Karinthine: $\mathfrak{c} =$ greenish blue, $\mathfrak{b} =$ dirty olive-green, $\mathfrak{a} =$ yellowish to colorless. $\mathfrak{c} = \mathfrak{b} > \mathfrak{a}$; ext. -14°; hemitropic lamellae; grown together with glaucophane. Glaucophane: $\mathfrak{c} =$ ultramarine blue, $\mathfrak{b} =$ purple violet, $\mathfrak{a} =$ yellowish to colorless; ext. -15° (probably not on (010)); $\gamma - \alpha$ as usual. $\gamma - \beta = 0.006$; 2 V large. In some lamellae a colorless zone occurs between glaucophane and karinthine. Karinthine passes into chlorite.

VI. 3. Loc.? Ilmenite with leucoxene, chlorite, actinolite. Hornblende (karinthine or soretite): $\mathfrak{c} =$ dark brown green, $\mathfrak{b} =$ brown-green, $\mathfrak{a} =$ straw yellow, with edges of bluish karinthine and here and there patches of glaucophane, especially on the prolongation of a chlorite vein. Karinthine shows hemitropic lamellae. Ext. -19°, $\gamma - \beta = 0.009$ ca.; axial plane (010); 2 V large; negative.

Eclogite. Hilton gulch, Oak Ridge. VII. 5, 9, 6.

Epidote and zoisite, margarite, rutile, inclosed in amphibole and free, titanite. Karinthine: ext. -23°; negative; 2 V large; axial plane, parallel to (010); with edges and patches of glaucophane in pale colors.

Glaucophane schist. Belmont School, Belmont. VII. 19.

Margarite, much titanite (leucoxene) with centers of rutile, lawsonite, chlorite in veins and fissures. Glaucophane in colors of medium intensity; karinthine: $\mathfrak{c} =$ bluish green, etc. Ext. -23°.

Epidote schist. VII. 20.

Much epidote, margarite. Karinthine: $\mathfrak{c}$ = blue, $\mathfrak{b}$ = dirty olive-green, $\mathfrak{a}$ = yellowish; ext. -19°; 2 V very large. Glaucophane in pale colors; $\mathfrak{c}$ = azure blue, $\mathfrak{b}$ = violet, $\mathfrak{a}$ = yellowish to colorless; ext -5°; 2 V small; negative.

Quartzite (gneiss). Belmont. VIII. 6, 7, 8, 9.

Brown garnet, magnetite, leucoxene, hematite, rutile, ilmenite, muscovite, glaucophane in pale colors as sheaves and radial spherulites.

Quartzite. Pine Flat, Sonoma County. VIII. 10, 11, 12.

Garnet, zoisite, leucoxene, ilmenite, hematite, muscovite (paragonite?) iron biotite. Glaucophane: $\mathfrak{c}$ = Prussian blue; ext. -6°; negative, 2 V small; with patches and nucleus of karinthine: ext. —18°, $\mathfrak{c}$ = bluish green, etc.; axial plane parallel to (010); 2 V large, negative. Polysynthetic lamellae. Here also the *actinolite with transverse axial plane* described above.

Eclogite. Reed Station, Tiburon.

Karinthine (or soretite) as lamellae with end faces: $\mathfrak{c}$ = bluish green, $\mathfrak{b}$ = olive-green, $\mathfrak{a}$ = yellow. Ext. ($\mathfrak{c}$:c) = -26° axial plane, (010); 2 V large; negative. Some lamellae with patches and edges of glaucophane. (Fig. 8.)

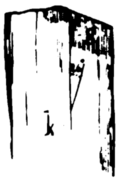

Fig. 8.—Karinthine crystal, **k**, with edges and zones of glaucophane. ×30.

Quartzite (and mica schist). Tiburon, 1½ miles southeast of Reed Station.

Idioblastic quartz with many inclusions of liquids with bubbles. Zircon, garnet in small crystals with optic anomalies, sometimes inclosed in crossites; titanite. Muscovite, bent in the crushed zones of the quartz. Brown iron biotite, often in radial lamellae, with a slight pleochroism: $\mathfrak{c}$ = dark brown, $\mathfrak{a}$ = yellow brown: negative, nearly uniaxial. Crossite: $\mathfrak{c}$ = violet, $\mathfrak{b}$ = Prussian blue, $\mathfrak{a}$ = yellow; it occurs as needles and lamellae; some needles recall those of tourmaline. Max. ext. —12°, $\gamma - \alpha = 0.002$, 2 V small, axial plane transversal to cleavage.

Glaucophane and titanite. San Pablo (studied and analysed by Blasdale, *loc. cit.*). No. 126. See my determinations on uniaxial glaucophane in the first part of this paper.

Glaucophane schist. North Berkeley.

Glaucophane, ext. -5½; on cleavage lamellae -7°: 2 V small; negative; $\gamma - \alpha$ and $\gamma - \beta$ as usual.

Glaucophane (boulder). San Pablo. No. 123. Analysed by Blasdale. The colors of the pleochroism not intense; ext. on cleavage lamellae, -10° (8°-10°), 2 V small.

Eclogite with glaucophane. Russian River. No. 2144.

Glaucophane quartzite. Wildcat Creek. North of Berkeley.

Garnet; titanite; glaucophane in pale colors, ext. -4°-6° on cleavage lamellae (one lamella gave -14°); the prisms have the orthopinacoidal faces more developed than the clinopinacoidal ones; 2 V very large.

Mica schist. North Berkeley.

Pale glaucophane, ext. on cleavage lamellae, -8°; 2 V large. Chlorite.

Quartzite. North of Berkeley.

Crossite quite identical with that of Palache. Very intensely colored; absorption and dispersion very large; max. ext. -20°; $\beta - \alpha > \gamma - \beta$; axial plane transverse to the prism; $\mathfrak{c}$ = opaque violet, $\mathfrak{b}$ = Prussian blue; $\mathfrak{a}$ = yellowish green.

SYENITES, ETC.

Syenite. Spanish Peak, Plumas County, California.

Apatite as needles and bunches; rutile as formless grains, often as pseudomorphoses of fragments of amphibole; leucoxene as halo around some rutiles, or as patches; ferruginous patches; chlorite and biotite with weak pleochroism, very small angle of the optic axes; negative. Albite, katophorite. Secondary quartz and crocidolite.

The katophorite is smoky yellow, without appreciable pleochroism; $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. The color seems to be due to a pigment which is not evenly distributed through the whole mineral; at all events, the periphery is lighter in color and clearer than the center. Sometimes the pigment forms zones and patches in the neighborhood of the clearer region, as if brought from there through secondary influences. A fibrous crocidolite occurs around and in some cavities of the katophorite in close connection with the light zones. Between crocidolite and katophorite there are always definite lines of demarcation, although the crocidolite zone begins with a greenish yellow substance. For katophorite: $\mathfrak{c}:c = -31^\circ$. The longitudinal and transverse sections show many hemitropic lamellae on the (100). The optic orientation as usual $\mathfrak{b} = b$; axial plane parallel to (010). 2 V large, positive; no appreciable dispersion.

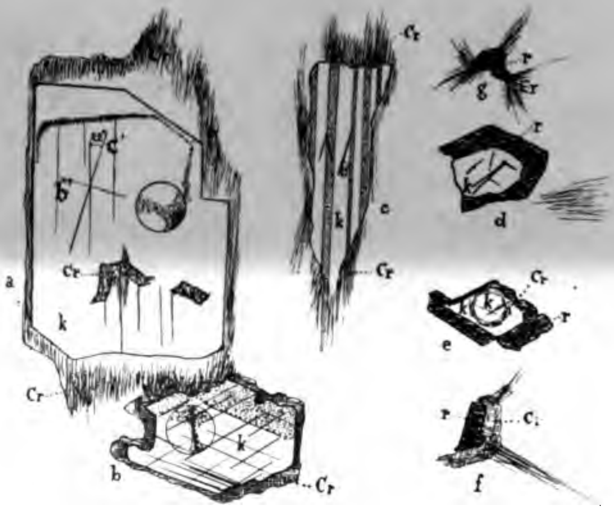

Fig. 9.—Katophorite, **k**, with halo of crocidolite, Cr. **a** = prismatic section; **b** = basal section; **c** = polysynthetic lamellae parallel to (100); **d** = pseudomorphs of rutile, **r**, after katophorite; **e** = kataphorite with a circle of crocidolite; **f** and **g** = same with halo or sheaf of crocidoliet. ×30.

Some fragments are very dark colored, and we find some grains of rutile surrounded by fibrous crocidolite: clearly they are pseudomorphs of katophorite. The pseudomorph is more distinct in some prisms which show a periphery of rutile and a center of katophorite with some fibers of crocidolite. (Fig. 9.) Very probably we meet here with the phenomenon of separation of the

TiO_2 from the Ti-bearing amphiboles during the transformation of the eruptive rock in a crystalline schist.*

The crocidolite was described above (Part I). The relations with katophorite are the same as in the rocks of Rosita Hills, etc. The angle of extinction of crocidolite ($\mathfrak{a}:c$) is opposite to that of katophorite.

Another specimen of the same syenite of Spanish Peak shows no katorphorite nor crocidolite; the structure is hypidiomorphic. The amphibole is here a soretite; it occurs as long prisms with (110) and (100) more developed than (010), with many inclusions of albite (and magnetite) in a poikilitic structure. Pleochroism: $\mathfrak{c}$ = greenish blue, $\mathfrak{b}$ = olive-green, $\mathfrak{a}$ = honey-yellow. $\mathfrak{c} \leqslant \mathfrak{b} > \mathfrak{a}$. Angle of extinction -24° ($\mathfrak{c}:c$); axial plane parallel to (010). $\gamma - \beta = 0.012$ ca. $\gamma - \alpha = 0.024$ ca. 2 V very large, negative. Apatite, chlorite, albite.

Quartz diorite. ¼ m. from Flume, Oak Ridge (5 m. east of Calaveras Valley). IV. 1.

Ilmenite, hematite, titanite as large reddish yellow, crystals, chlorite, biotite, acid oligoclase with crystals of lawsonite, pegmatitic and granophyric quartz.

Katophorite: $\mathfrak{c}$ = reddish brown (if altered: greenish or bluish); $\mathfrak{b}$ = olive brown, $\mathfrak{a}$ = light yellow. $\mathfrak{c} \geqslant \mathfrak{b} > \mathfrak{a}$. The colors not uniform, with dirty patches and zones; ext. -26°; hemitropic lamellae; axial plane parallel to (010); negative.

The katophorite passes over into fibrous crossite (?) at the periphery, as the katophorite from Spanish Peak does into crocidolite.

Ferruginous biotite as pseudomorphs of hornblende with zones of leucoxene or rutile, chlorite, and a bluish actinolite result also as a secondary product of katophorite.

CONCLUSIONS.

From this short description of some of the most interesting rocks of California we may conclude:

I. The glaucophane schists are in general crystalloblastic rocks:† lawsonite, epidote, zoisite, sometimes titanite, ilmenite, and even quartz are idioblastic elements. Sometimes the structure of the glaucophane schists is ophitoblastic.

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* F. Becke. Über Mineralbestand und Structur der Krist. Schiefer. C. R. IX. Congrès de Géologie, Vienne 1904.

† The nomenclature proposed by F. Becke, *loc. cit.*

2. The statement of Rosenbusch*, "die Arfvedsonitamphibole treten nur in Eruptivgesteinen, die Glaukamphibole dagegen nie als ursprüngliche Gemengtheile solcher, auf", is quite true.

3. The glaucamphiboles rich in Fe_2O_3 (crossite, rhodusite, etc.) are in general characteristic of the most acid schists (quartzites, albite schists, gneiss, mica schist with muscovite, just as arfvedsonite amphiboles rich in Fe_2O_3 (riebeckite, etc.) are characteristic of acid eruptive rocks† (pegmatites of granites, quartz syenites, etc.

4. The origin of the glaucophane schists is very complicated, and nothing but detailed investigations in the field will solve the problem. The phenomenon of the metamorphism of various rocks into glaucophane schists seems to be a kind of piezometamorphism (Weinschenk), as stated by S. Franchi.

5. Many kinds of amphiboles, glaucophane, karinthine, actinolite, etc., may be formed synchronously in the same rock and crystal.

6. During the metamorphism of the eruptive rocks into glaucophane schists, many changes of the homogenous mixtures into non-homogenous rocks take place. Besides the formation of rutile and titanite from brown amphiboles, of lawsonite (epidote, zoisite, lotrite (?), etc.) and albite from a basic plagioclase, the occurence of various amphiboles (glaucophane, karinthine, actinolite, etc.) can also be explained in this way from katophorite, barkevikite, etc., or a similar complicated amphibole.

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* *Loc. cit.*

† G. Murgoci. The Genesis of Riebeckite and Riebeckite Rocks. Amer. Journal of Sci., 1905.

Bukarest,
March, 1906.

UNIVERSITY OF CALIFORNIA PUBLICATIONS
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Vol. 4, No. 16, pp. 397-409 ANDREW C. LAWSON, Editor

THE GEOMORPHIC FEATURES OF THE MIDDLE KERN.

BY

ANDREW C. LAWSON.

Two years ago the writer published a paper* descriptive of the genesis of the salient features of the Upper Kern Basin, in which one of the most interesting points was the recognition of a great rift which had determined the course of the Kern Cañon. The rift was traced as far as the southern end of the Trout Meadows defile which was the limit of the writer's field observations. With the object of extending those observations, the writer last summer made a somewhat hurried trip through the middle Kern Cañon in the hope of discovering evidence of the prolongation of the rift to the south of the junction of the Little Kern with the Kern River. The most convenient approach to this portion of the mountains is by the wagon road from Caliente at the southern end of the Great Valley, by way of Walker Basin, Havilah, and Hot Springs Valley to Kernville, and thence up the Kern Cañon by a saddle trail to the mouth of the Little Kern. On this route of travel certain observations were made which it is here desired to record. From Caliente, altitude 1286 feet, the road follows the terraced cañon of Caliente Creek for a few miles with a very gentle grade and then climbs up to the left in the steep-grade cañon of Oyler Creek to a summit, on the north side of which there is a rapid descent to Walker Basin. The summit is ten miles distant from Caliente and about 2800† feet above it, or 4086 feet above sea level. From this summit the observer looking north obtains a fine view of the profile of Breckenbridge Mountain, and of Walker Basin, both very remarkable geomorphic features. Breckenbridge Mountain is an asymmetric ridge, the general trend of which is north and south, and which lies immediately to the west of Walker Basin. The summit is probably about 6500 feet above sea level. Its western slope is exceedingly gentle and descends uniformly toward the great valley in the latitude of Bakersfield. Its eastern side is a very precipitous mountain front overlooking Walker Basin. The mere inspection of the profile suggests immediately that the mountain is a tilted orographic block and that its eastern front is a fault-scarp. This suggestion is confirmed by its relation to Walker Basin. The latter is a triangular shaped valley having an area of ten or eleven square miles. One side of the triangle is the base of the steep eastern face of Breckenbridge Mountain, and the other two sides converge in a narrow cañon at a point about four miles to the east of the mountain base. The valley bottom is wholly alluviated with a nearly flat slope to the west. It stands at an altitude of about 3300 feet above sea level. It is in entire geomorphic discordance with the erosional features of the surrounding mountains. On all sides are narrow high-grade cañons and gorges. The outlet of the basin itself is a narrow gorge, which lies between the south end of Breckenbridge Mountain and the ridge over which the road passes from Caliente. This geomorphic discordance with the erosional features of the region can only be explained as the result of an acute deformation, such as would be produced by uplift of an orographic block along a fault parallel to the east front of Breckenbridge Mountain.

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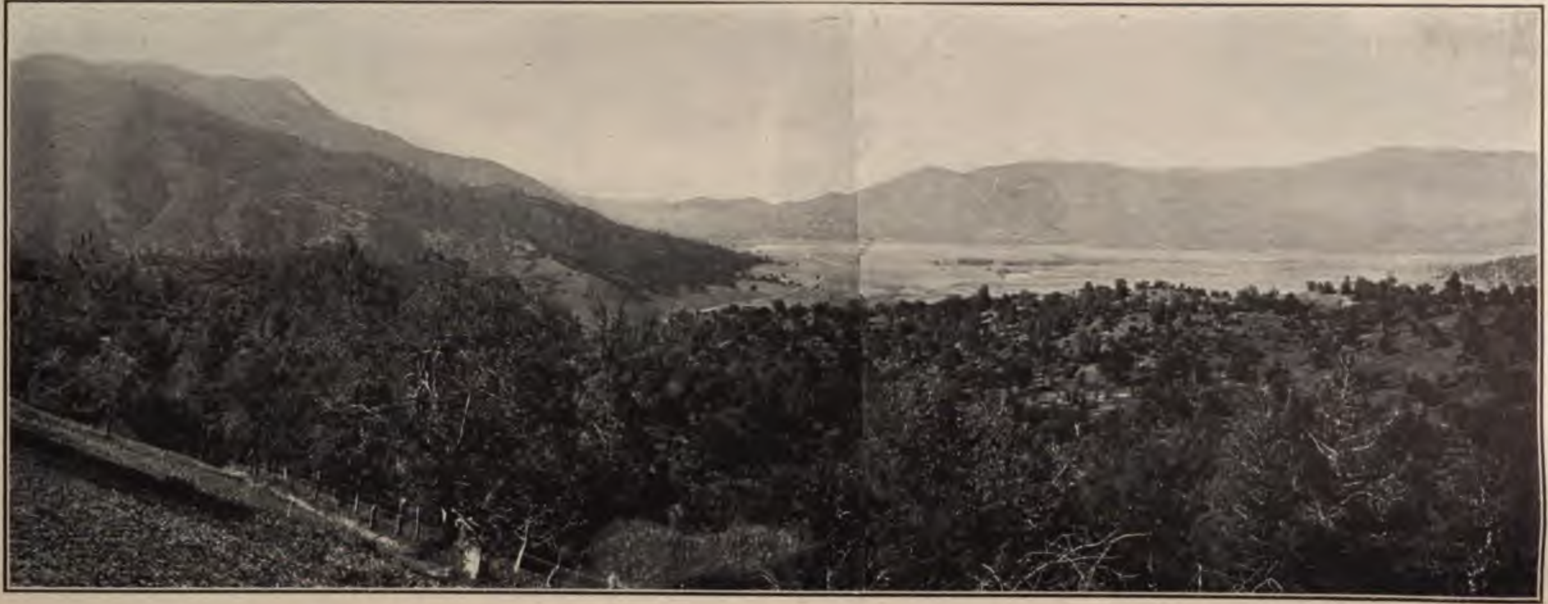
* Geomorphogeny of the Upper Kern Basin. Bull. Dept. Geol. Univ. Cal., Vol. 3, No. 15.

† Aneroid.

The route to Kernville follows the east side of this great mountain scarp from the southwest corner of Walker Basin to Hot Springs Valley, a distance of fifteen miles with a bearing a little east of north. From the northwest corner of Walker Basin the road ascends about 1000 feet to cross a divide which connects the lower portion of the Breckenbridge scarp with the mountains to the east and separates Walker Basin from a much narrower depression in which Havilah is situated. This is a



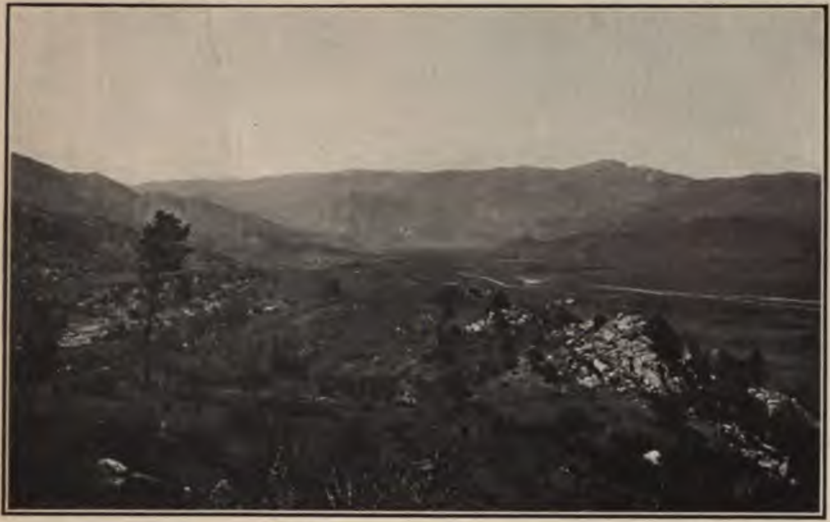
Breckenbridge Mountain and Walker Basin. A fault-scarp overlooking an alluviated valley.

longitudinal valley lying between the scarp and the mountains to the east. In its lower part it has been alluviated, but the alluvium is now dissected by the stream which drains the valley to the Kern. This drainage is by a narrow gorge which lies between the scarp and a mountain spur from the east which separates Havilah Valley from Hot Springs Valley. The extension of the scarp beyond the Kern, if it persists, lies in a rugged country difficult of access and was not pursued further. Beyond the Kern at the point where the drainage from Havilah Valley enters it, Breckenbridge Mountain may have its counterpart in the Greenhorn Mountains, but this ridge is not known to present an abrupt scarp to the east such as exists to the south of the Kern, and it is much more symmetrically dissected with reference to its north and south axis. It would seem probable, therefore, that the Breckenbridge fault dies out about where the Kern river crosses it and that beyond this point the deformation of the region took, in part at least, the form of an arch, the erosion of which gave rise to the Greenhorn Mountains. Havilah Valley then may be interpreted as a structural trough, formed at the time of the faulting along the Breckenbridge fault, which has been considerably modified, first by alluviation before its outlet had cut back along the lower part of the trough, and subsequently by stream erosion. But while it appears probable that the Breckenbridge uplift was continued in part beyond Havilah as an arch, it was also in part extended, as will appear in the sequel, as a fault of more moderate throw to the east of this arch up the cañon of the Middle Kern.

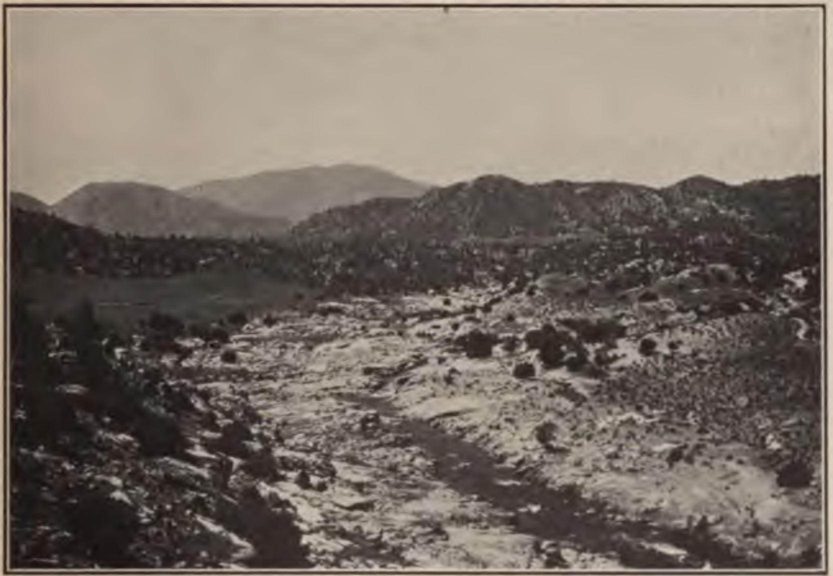
The next point of interest on our route of observation is Hot Springs Valley. This is reached from Havilah by a road which crosses a notch in the mountain spur above referred to. The descent from this divide to the Hot Springs is about 1300 feet and the latter are situated at an altitude of about 2600 feet. This pass over which the road passes from Havilah to Hot Springs Valley is asymmetric in cross profile and has a steep straight wall on the west side which is strongly suggestive of a degraded fault-scarp.

Hot Springs Valley from Vaughn at its southern end to Isabella at the junction of the South Fork with the Kern River is a little over four miles long and is about a mile wide. Its trend is north-northeast and south-southwest. This valley is divided longitudinally into two parts by a low median ridge of granitic rock. On the east side of this ridge is a flat bottomed alluviated plain from one-half to three-quarters of a mile wide. In this plain are situated the Hot Springs from which the valley is named. The springs emerge from the alluvium of the plain in its middle part but toward the east side. On the west side of the median ridge is the somewhat tortuous channel of the Kern River. The stream flows in a succession of low rapids with intervals of smooth water over bare granite with a descent of about 25 feet to the mile. The trench in which the stream flows is a typical erosional feature. The stream enters this rocky trench through a stream-worn notch in the north end of the median ridge immediately at the junction of the South Fork and the Kern River near the town of Isabella. Here we encounter a totally different character of stream bed, the moment we pass to the east of the median ridge. Both the Kern and the South Fork are flowing upon expansive and far extended flood plains and their confluence occurs upon a common flood plain. This flood plain strewn with boulders and gravel extends north up the Kern for a distance of over ten miles from Isabella with a breadth diminishing from a mile and a half to a few hundred feet. Up the South Fork to the east it extends for probably fifteen miles, with a width in its lower part of over a mile. But here the flood-plain silts and sands mantle the stream gravel in large part and make agricultural land. Above the present flood plain is a terrace about 25 feet in height, indicating that the valley at one time was filled that much higher than at present. The alluviated plain which forms the eastern moiety of Hot Springs Valley is about on the grade of this terrace.

To complete the description of that portion of Hot Springs Valley which lies to the east of the median ridge, it should be stated that the alluvium which forms its floor is derived from three incoming streams. The largest of these is Erskine Creek, which enters the valley at its southeast corner and there builds up a notable fan which spreads out over its entire width. The second is Vaughn Creek which enters at the south end and gives



A. Looking north along the median ridge of Hot Springs Valley from a point opposite Hot Springs, showing the dual character of the valley.



B. Looking down the rocky course of the Kern on the west side of the median ridge of Hot Springs Valley.

rise to a less important fan which is confluent with that of Erskine Creek. The smallest creek is that which drains an incipient cañon in the face of the steep mountain slope which bounds the valley on the east side between Erskine Creek and the South Fork. This creek lies to the north of the Hot Springs and the latter are situated in a depression between its fan and that of Erskine Creek. For half a mile around the springs the soil in dry weather is white with an incrustation of alkaline salts. But this is more probably referable to seepage from the lower edge of the fans than to the water from the springs.

The median ridge which divides Hot Springs Valley into two parts is continuous from Isabella to a point opposite the Hot Springs where it attains its maximum height of about 400 feet above the flat valley floor to the east. South of this point there is a notch in the ridge which is on a level with the west side of the flat valley and about 60 feet above the Kern. Beyond this to the south the ridge is lower and in less than a mile there is another notch in the ridge cut below the level of the valley floor through which Erskine Creek finds its way to the Kern. At the southern end of the ridge there is still another notch which separates it from the mountain slope which forms the south boundary of the valley. Through this notch Vaughn Creek flows to the Kern with a drop of nearly 100 feet.

From the above brief outline of the geomorphic features of Hot Springs Valley, it is evident that we have here to deal with conditions induced by diastrophic interference with the normal course of erosional evolution. Below Hot Springs Valley the Kern flows in a normal mountain gorge. Above their aggraded flood plain at their confluence, both the Kern and the South Fork flow in sharp, deep cañons. Two anomalies are to be accounted for: The first is the aggradation of both streams above their confluence and the second is the dual character of Hot Springs Valley.

It has been pointed out that the asymmetric ridge of Breckenbridge Mountain with its steep eastern fault-scarp passes in part northerly into the more symmetrical ridge of the Greenhorn Mountains, on the east side of which no great scarp has been detected. It has been further suggested that the deformation which resulted in faulting along the face of Breckenbridge Mountain found its expression in arching in the Greenhorn Mountains. Now the Greenhorn Mountains lie to the west of Hot Springs Valley and any deformation such as is here suggested would have the tendency to pond back the Kern. That tendency would, however, be effective only if the corrasive action of the Kern failed to keep pace with rate of uplift. But for several miles below the region of aggradation, and still on the east side of the uplift, the Kern is flowing in a rocky trench and it would thus appear that the Kern had been fully able to keep pace in its rate of down-cutting with the rising arch in its path. We cannot, therefore, adduce this special phase of the deformation of the region as the cause of the aggradation of the Kern and the South Fork above their confluence; and even if such a cause were admitted, it would offer no explanation of the dual character of Hot Springs Valley. No amount of simple aggradation due to the ponding of the Kern would account for the notched median ridge between the two portions of the valley. A more fruitful hypothesis is suggested by the notches in this ridge. They have the character of very short residual trunks of beheaded stream valleys. If such be their origin, then the valleys or cañons of which they once formed a part could only have been beheaded by a fault along the east side of the median ridge, with a downthrow to the east. The straight and quite precipitous east side of the median ridge becomes under this hypothesis a degraded fault-scarp, the notches in which are antecedent to the existence of the ridge. Does this hypothesis afford an adequate explanation of the two classes of phenomena with which we are here concerned? Seemingly it does. By the development of a fault along what is now the east side of the median ridge with a downthrow to the east, a trough would be formed, the aggradation of which would give us the flat bottomed eastern moiety of Hot Springs Valley. If the fault-scarp were rather rapidly formed, as it probably was, the waters of the Kern would be impounded against it and a process of aggradation inaugurated. The impounded waters would rise to the level of the lowest notch in the face of the fault-scarp, which would probably be the trench of the Kern itself, and so resume their former channel

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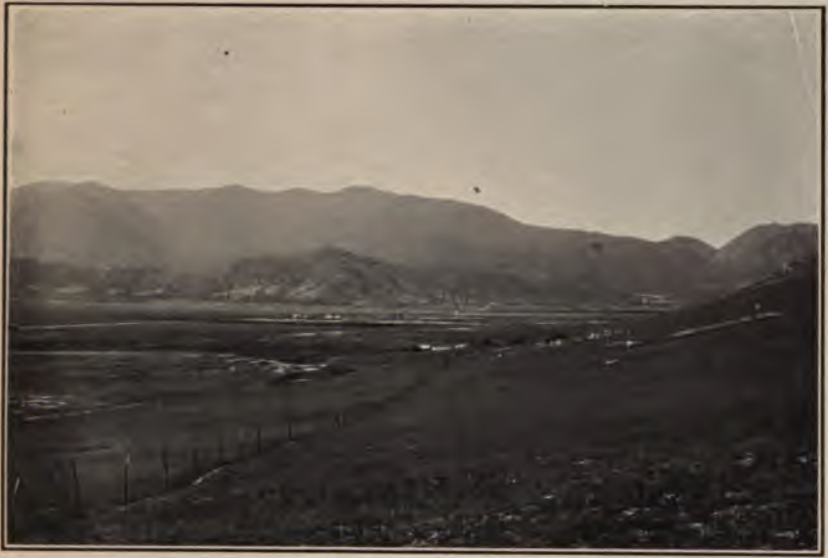
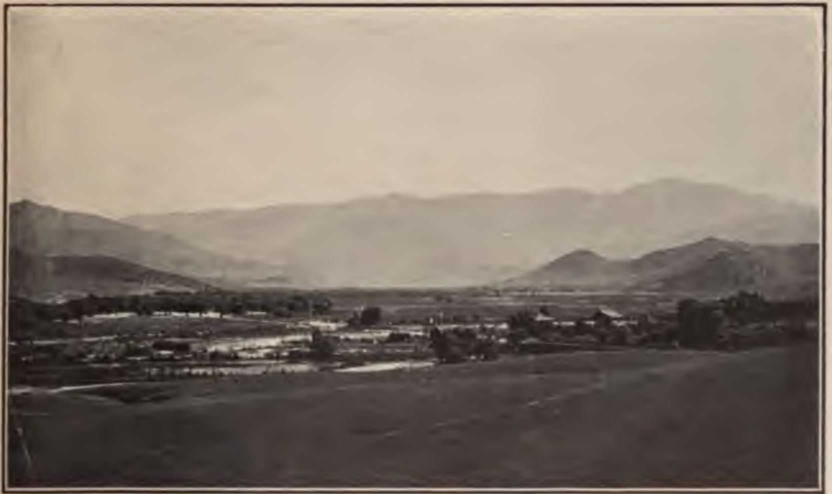


A. View of east part of Hot Springs Valley, looking southeast. Fault-scarp of median ridge on the right.



B. Expansive flood-plain at the confluence of the South Fork and the Kern at Isabella.

beyond the scarp. Owing to the impounding of the stream detritus in the lake thus formed, the downward corrasion of the trench beyond this notch would be slow. Meanwhile deltas would be rapidly extended down the Kern and South Fork arms of the lake. The embayment of the lake to the south of Isabella would be filled partly by the silt of the river and partly by the deltas of Erskine and Vaughn Creeks. The final result would be an expansive flood plain sloping up in all directions from the rock barrier in the notch of the fault-scarp through which the river passed out to its normal channel. As soon as the flood plain was completed by delta extension on to this point, coarse detritus would begin to pass through the notch and the deepening of the Kern trench beyond the scarp would proceed comparatively rapidly. In consequence of this, the flood plain would be dissected leaving terraces at the level of the flat floor of the infilled trough to the south of Isabella.

Pursuing now our observations up the Kern River above Kernville, we find the stream flowing in a profound but remarkably straight cañon. The general trend of the cañon is much more nearly a straight line than is the course of the stream which flows in it. On the west side of the cañon the crest of the mountains is in general about ten miles back from the river. Numerous tributary streams enter from this side and all of them, as far as Tobias Creek, twenty miles above Kernville, have built up huge alluvial cones which indicate a marked lack of accordance between the action of these affluents and the main stream, which is itself running on bedrock and deepening its trench. The material of these cones is in large part of a very coarse bouldery character. It seems probable that the deformation of the country on this side of the Kern which has been recognized in Breckenbridge Mountain and in the Greenhorn Mountains has in late Quaternary time accentuated the grade of the upper reaches of these affluents and caused them to deject great quantities of alluvium into the main cañon. It is even quite probable as an inference from the existence of these cones that, if the country a few miles back from the stream were examined, a fault scarp would be discovered, the dissection and degradation of which has given rise to the alluvium.

Beyond Tobias Creek for the next twenty miles to the mouth of the Little Kern, no such alluvial cones are found on this side of the Kern. The trail for this stretch of the cañon passes over a rolling terrace, the more expansive portions of which are known as Dry Meadows, Peppermint Meadows, and Kern Flats, the last being the high terrace of the Little Kern described in a former paper.* This rolling terrace is mantled with a heavy regolith of decomposed granite. Occasionally residual hills rise above its average surface and the streams which cross it from the high ground behind it do so in open swails and then plunge suddenly through chasms to the Kern which flows at from 1200 to 1500 feet below. It is evident that this rolling terrace is a remnant of a very mature valley land which has been dissected by the down-cutting of the Kern, and is to be correlated with little question with the high valleys of the upper Kern. At the confluence of the Kern and Little Kern this high valley is mantled with lava as more fully described in the paper† above referred to. It appears, however, that the writer did not from his former observations fully appreciate the degree of inequality of the lava-mantled surface. The dissection of the Kern Flats by the Little Kern shows that the lava is in places 400 feet thick. This would indicate that the surface prior to the outflow of lava was similar in its degree of relief to the very mature but rolling valley remnants at Dry Meadows and Peppermint Meadows. There can be little doubt that these high valley remnants once formed a continuous valley through which the Kern flowed anterior to the general uplift of the Sierra Nevada which inaugurated its dissection. It was, however, a more or less sinuous valley and in its dissection one portion has been isolated from another. Thus Kern Flats are separated from Peppermint Meadows by a mountain spur, known as the Needle Rock, which extends out to the west wall of the deeper portion of the cañon. Similarly a mature rounded divide which separates Peppermint Meadows from Dry Meadows reaches the deeper part of the cañon and the trail from one meadow to the other has to cross this divide. The notable features, then, of this side of the Kern cañon between Kernville and the Little Kern are: (1) The extension for twenty miles below the Little Kern of the same high valley system as was formerly noted in the Upper Kern basin. (2) The absence of alluvial cones where the valley terraces prevail. (3) The prominence of alluvial cones between Tobias Creek and Kernville where the valley remnants fail. (4) As an inference from these facts a probable rather acute diastrophic disturbance of the latter stretch of the cañon on its west side.

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* Bull. Dept. Geol. Univ. Cal. Vol. 3, No. 15.

† *Op. Cit.*

The geomorphic features of the east side of the Kern Cañon from the vicinity of Kernville to the mouth of the Little Kern are in remarkable contrast to those of the west side. In general the east side of the cañon is more precipitous than the west side, and it appears to be the edge of a high uneven plateau. The streams are shorter and frequently fall in cascades over the steeper portions of the cañon wall in notches of no great depth. The Kern in the first twenty miles of the stretch under consideration is crowded to the east side of the cañon by the large alluvial cones on the west side and similar cones are only feebly developed on the east side. These facts indicate in themselves a rather striking contrast in the geomorphic aspects of the two sides of the cañon, but the most notable feature of the east side, and one which is entirely absent on the west side, is a series of high and prominent ridges and butte-like peaks which are arranged along the cañon side in an almost straight line. These ridges and buttes extend along the whole length of the cañon from near Kernville to the Little Kern. They lie within the cañon and reach in general from about one-half to two-thirds the height of the cañon wall, and they are separated in each case from the main cañon wall by a defile or col which is generally several hundred feet lower than the summit of the ridge or butte. Between these ridges or buttes flow transversely the affluents of the Kern from the notches in the main cañon wall. The entire series presents the appearance of a continuous ridge, separated from the main cañon wall by an equally continuous narrow defile, which has been dissected by the affluents of the Kern which now pass through it. In attempting to explain these remarkable features the writer has considered several hypotheses. It is possible that they might have originated wholly by the subsequent erosion of lateral branches of the affluents of the Kern if we suppose the existence of a zone of exceptional weakness paralleling the main cañon wall. Such a zone of exceptional susceptibility to stream erosion might inhere in the character of the rocks themselves or it might be purely a structural feature such as a rift, which, it may be recalled, was found to exist along the cañon of the Upper Kern in what is practically the projection of the line we are now considering. As regards the possibility of a zone of weakness in the rocks themselves, it is to be noted that for several miles along the cañon of the Kern there is a belt of crystalline schists which is sunk down into the granitic rocks of the region in much the same way as is the similar belt of schists at Mineral King described by Knopf and Thelen.* These schists are, however, common to both sides of the cañon, whereas the peculiar features noted are confined to the east side. In several cases, noted only from the trail on the west side of the cañon, the ridges and buttes are composed chiefly of crystalline schists, in other cases of a mixture of crystalline schists and granitic rocks, and in other cases toward the upper end of the cañon they appear to be composed chiefly of granitic rocks. It would appear, therefore, that there is no good warrant for assuming a zone of weak rocks which might be easily removed by subsequent erosion so as to produce in straight alignment the series of defiles which separate these ridges and buttes from the main cañon wall. Moreover, if such a zone of weak rocks existed, it would undoubtedly have been discovered by the Kern in the course of its downward corrasion and have become the main line of cañon cutting. But the main course of the cañon crosses granite and schists indifferently and has evidently not been greatly influenced in its course by peculiarities of these rocks.

We are forced, then, still under the assumption that the series of defiles is due to subsequent corrasion along a line of weakness, to the view that the weakness postulated must be structural, a line which is common to both granite and schists. Such a structural line might have existed prior to the development of the Kern Cañon, or it may have come into existence after the cañon trench in its main features had been established. If the first

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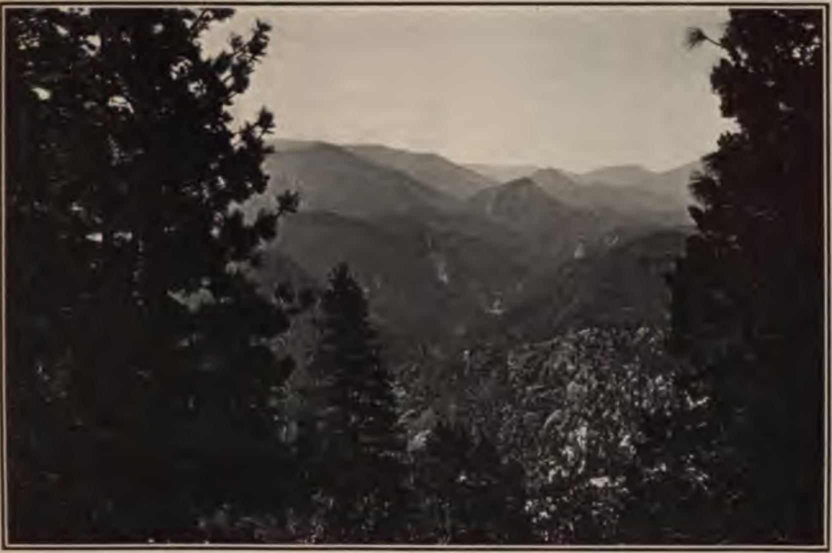
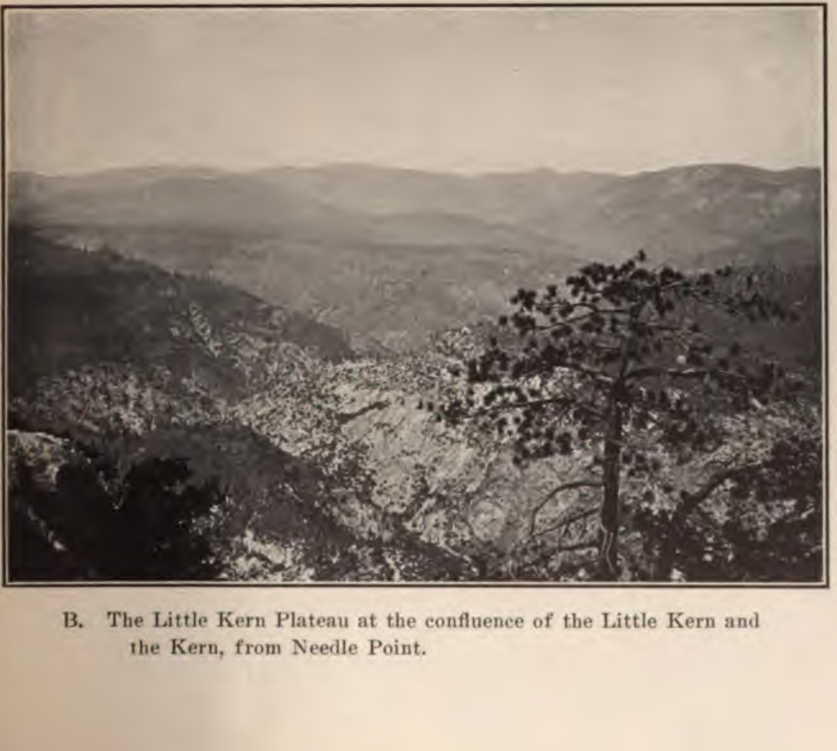
* Bull. Dept. Geol. Univ. Cal. Vol. 4, No. 12.



A. Looking down the cañon of the Kern from Needle Point, showing line of buttes and ridges on the east side.



B. The Little Kern Plateau at the confluence of the Little Kern and the Kern, from Needle Point.

were the case, then it is difficult, as before, to see why it should not have determined the main line of cañon corrasion instead of the one now followed by the stream. If the supposed structural line, a rift for example, had come into play after the main cañon trench had been deeply incised, results might ensue by subsequent corrasion which would be consistent with the facts observed. We have in this set of assumptions, therefore, a possible explanation of the phenomena. It is, however, less probable than another hypothesis discussed below.

Another hypothesis which the writer attempted to apply was suggested by the resemblance of these features to the kernbuts of the Upper Kern and the possibility of their having the same origin was considered. The analogy of these features with the kernbuts breaks down, however, under examination. In the Upper Kern Cañon the kernbuts cause constrictions in the cañon and in the interval between them the cañon bottom has its full width. In the case of the ridges and buttes of the Middle Kern, the width of the lower portion of the cañon is not affected by their presence. The intervals between the buttes and ridges are purely erosional products and the prominences which are thus separated cannot be regarded as portions of a long narrow fault block which have failed to sink as far as the intervening portions.

There are two other hypotheses which must be examined as possible explanations of the phenomena under consideration. Both of these involve faulting and they differ essentially in the position of the fault, its hade, and the direction of the downthrow. The first of these supposes that the long but now dissected defile was originally the trench of the Kern, and that when in the course of its downward corrasion it had reached this depth, a fault occurred on the west side of the cañon with a downthrow to the west. In this way a trough might be formed deeper than the trench of the Kern and into this the drainage would naturally flow leaving the old channel stranded above the brink of the new diastrophic cañon. The erosional modification of this stranded channel and of the ridge between it and the new channel might give us the feature we are seeking to explain.

The second hypothesis states that after the cañon of the Middle Kern was well advanced, a fault occurred within the cañon but on the east side with downthrow to the east. The trough thus formed was not as deep as the cañon when the dislocation occurred. Again by erosional modification of the purely diastrophic features the present forms would be evolved. In this case the notches in the ridge between the older erosional cañon and the new diastrophic trough would be antecedent to the dislocation and would correspond to the affluents of the Kern. In making a choice between these two diastrophic hypotheses the facts which have been narrated in the earlier part of this paper seem clearly to limit us to the second. It has been shown that from the south end of Walker Basin through Havilah Valley, and Hot Springs Valley on the same line as that on which the Middle Kern flows, there has been a very notable downthrow to the east and an uplift to the west along a north and south fault. It would seem necessary, therefore, if we resort to faulting to account for these remarkable geomorphic features of the cañon of the Middle Kern that we must adopt the fault hypothesis which gives us the same downthrow. By doing this, moreover, the series of ridges and buttes which adorn the east side of the cañon of the Kern consists with and is the perfect analogue of the median ridge of Hot Springs Valley from the genetic point of view. The same considerations which favor this hypothesis as against the one which postulates downthrow to the west on a fault on the west side of the cañon are adverse to the first hypothesis considered, viz: the evolution of the trough or defile by purely erosional processes along a rift developed within the cañon but without dislocation. The fault line along which the country was downthrown to the east from Walker Basin to Kernville would pass straight up the cañon of the Middle Kern and there seems to be no good reason for doubting that the peculiar features of the cañon are just as much the result of that faulting as are the equally remarkable features described to the south of Kernville.

The question now arises: Is the occurrence of a fault within the cañon of the Kern and strictly coincident with it in direction more than a coincidence? In view of the observations made on the Upper Kern* it is clear that it is not merely a coincidence.

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* *Op. cit.*

For the Upper Kern the conclusion was reached that the cañon had been controlled as to its course by a rift line antedating the cañon and that at a later period faulting had occurred along this rift with partial engulfment of a narrow orographic block or wedge. The Middle Kern lies along the southward projection of this rift line through the Trout Meadows defile, and there seems little room for doubt but that its course, like that of the Upper Kern, was determined primarily by a great north-south crustal rift. At a later period when the cañon had been deeply incised the region was deformed and dislocation was effected along the general line of the rift.

University of California,
April, 1906.

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NOTES ON THE FOOTHILL COPPER BELT OF THE SIERRA NEVADA.

BY

A. KNOPF.

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INTRODUCTION.

The existence of a belt of copper deposits along the western foothills of the Sierra Nevada has long been known, but its economic importance has been overshadowed by the richness of the Gold Belt immediately to the east of it, and by the extensiveness of the copper deposits of Shasta County.

Owing to the discovery of rich carbonate croppings in Calaveras County, California experienced an intense copper excitement as early as 1861. Upon the exhaustion of the oxidized ores a period of stagnation and idleness ensued, lasting well up to the present time. Only within the past decade has an extensive exploitation of the unaltered sulphide bodies commenced, notably at Campo Seco and Copperopolis.*

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* For an account of the historical and economic features of the copper resources of the State, Bull. 23 of the Cal. State Mining Bureau should be consulted.

The formations of the Sierra Nevada region are according to the United States Geological Survey grouped together as the Bedrock Complex and the Superjacent Series. The Superjacent Series is composed of the Tertiary auriferous gravels of fluviatile origin, and the succeeding heavy accumulations of rhyolites, andesites, and basalts, all resting upon the eroded edges of the Bedrock Complex. This Complex includes a succession of closely appressed rocks in belts paralleling the general trend of the range, and dipping steeply towards its axis. They comprise quartzites and microcrystalline mica schists (Calaveras formation, Carboniferous), black clay slates (Mariposa formation, Upper Jurassic), meta-andesites and their schistose equivalents. At the close of the Jurassic these were all extensively intruded by plutonic magmas, chiefly granodorites and peridotites.

The meta-andesites and their associated pyroclastics often attain enormous thicknesses, freqently reaching five miles, without doubt, however, due in great part to folding, although as yet unrecognized in the field.* In the earlier folios of the Gold Belt they were mapped as diabases and augite porphyrites, but in the later publications (notably the Mother Lode Folio, F. L. Ransome) they were designated meta-andesites in order to emphasize their essentially extrusive character. Their exact position in the stratigraphic column is still a moot point in the geology of the Sierra Nevada, though the evidence, both petrographic and stratigraphic, favors a late Jura-Trias age for the bulk of the series.

We propose to describe the copper deposits in geographic order from north to south. A number of small idle or unworked prospects were not visited.

SPENCEVILLE, NEVADA COUNTY, AND VICINITY.

North of Spenceville toward the head of Little Dry Creek numerous copper prospects have been opened up in the meta-andesites. The country rock is usually massive, but in the vicinity of the copper deposits has been slickensided and sheared, and belts of strongly foliated chloritic schists up to 4 feet thick have been produced. The strike is N. 45° W. and the dip vertical.

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* H. W. Turner, Jackson Folio.

Clay and gouge are frequent, as on the other hand are lenses of massive, unsheared rock in the midst of the schists. The ore consists of chalcopyrite in a gangue of a spherulitic zeolite (Sp. gr. 2.17) replacing a chlorite schist. The microscope shows radial stilbite,* quartz charged with liquid inclusions, areas of chlorite, often consisting of small partially developed spherulites, and accessory epidote and calcite. The most nearly massive wall rock obtainable is composed largely of green, reedy hornblende, chlorite, highly altered plagioclase, and accessory epidote, pyrite, and magnetite.

At Spenceville the ore body occurs in andesites whose extrusive character is readily apparent. Facies carrying numerous quartz amygdules occur in the bed of Little Dry Creek, and the cryptocrystalline facies on the brow of the hill just behind the mine dump is rich in epidote amygdules. A few hundred feet to the west, however, typical ophitic diabase occurs. This has been cut by fine grained dykes of similar chemical composition. The dykes show that minor faulting has taken place, not exceeding half a foot in individual cases. Some two hundred feet east of the Spenceville mine the greenstones are intruded by a large granodiorite boss. Lindgren has characterized the Spenceville deposit as a "local massing of copper on the granodiorite contact."†

The mine has been a quite large producer in the past, but is now idle and filled with water. From report it appears that the ore body consisted of one huge kidney of chalcopyrite which pinched out in depth.

PINE HILL, NEVADA COUNTY.

This locality has been described by Lindgren, who drew attention to the unusual fact that here barite acts as a carrier of gold.‡ The deposit was characterized as of the general type; "veins and seams of barite, carrying gold and silver, distributed through a kaolinized zone in diabase and diabase porphyrite." Since 1892 more development work has been done, but at present the mine is tied up by litigation, and the shafts flooded with water.

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* The optical properties of this zeolite diverge from those of stilbite in two important particulars; it shows an absorption equal to that of muscovite, and displays brilliant interference colors of the 2nd and 3rd orders. Otherwise the physical and chemical properties are identical with those of stilbite.

† Smartsville Folio.

‡ W. Lindgren, The Gold Deposit at Pine Hill, California; A. J. S. 3rd ser., vol. XLIV., pp. 92–96, 1892.

Pine Hill itself consists of augite andesites, ophitic diabases, amygdaloids, and tuffs. Intercalated with the porphyries is a lens of fissile black slate 50 feet thick. Near the summit of Pine Hill the tuffs have been crumpled and brecciated. This has been the locus of most intense mineralizing activity. Extensive gossan croppings often containing much heavy spar have formed. Large masses of pure solid barite occur. The gossan when panned yields numerous coarse colors of gold. The pure barite assays $2 per ton.

Tunnels run into the hill show that the porphyries have been thoroughly leached by sulphuric acid. They still retain their porphyritic aspect, but are soft enough to be kneaded. A very white kaolin, theoretically pure,* is of frequent occurrence, but seems limited to zones of movement. This movement may be correlated with the arching upward of the floors of abandoned drifts—1 foot rise in 4½ feet. The tunnels show that the porphyry has been fractured and stained with iron oxide along the cracks and fissures. At open spaces porous platy masses of limonite have formed, and lying loosely upon these are numerous small glassy crystals of barite.

The gossan has long been mined as a free milling gold ore. At 75 to 100 feet in depth oxides, carbonates, and native copper were encountered, and the barite disappeared. The copper ore below this consists of a crumbly mass of bluish black sulphide in which the frequent glint of pyrite can be detected. A thin section of leaner ore shows grains of pyrite surrounded by peripheral coatings of copper sulphide. The gangue is fine grained quartz. Unfortunately, the flooding of the mine did not admit of a closer investigation of the extent of the secondary enrichment.

THE VALLEY VIEW GROUP.

Dairy Farm Mine.—A large lens of solid pyrite 60 feet thick, carrying 2 per cent. copper, parallel to the foliation of the enclosing schists, is reported from here. Amphibolite schist is the prevailing country rock, but numerous lenses of quartz porphyry schist occur in the immediate vicinity.

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* W. Lindgren, *loc. cit.*

Valley View Mine.—The gossan deposit here has been worked for gold during many years.* At greater depth chalcopyrite and covellite were struck. Development is in active progress.

The gossan occurs in a quartz porphyry schist lens, some three hundred feet wide and nearly a thousand feet long, intercalated in the prevailing amphibolite schists.

Cedar Mine, near Wolf Creek.—The country rock is meta-andesite and augite porphyry tuff, roughly schistose N. 60° W. The ore is chalcopyrite in a gangue of quartz and calcite. The vein is a strong fissure vein, about 20 feet wide, breaking at right angles across the country. Inclusions of country rock occur in the gangue. The property is at present idle.

Two miles south of this is the Ace Mine, also idle. The shafts are sunk upon a mineralized shear zone in the otherwise massive meta-andesite.

CAMPO SECO, CALAVERAS COUNTY.

Just west of the Campo Seco copper mines is a belt of black clay slates (Upper Jurassic age†). Passing eastward across the strike these graduate by an easy transition, as seen at the old engine house, into tuffs and coarse breccias, more or less schistose. A typical specimen of these greenstone schists examined microscopically showed a large abundance of chlorite and epidote, especially the latter, and a few small plagioclase feldspars. Intercalated with these breccias are some green glossy slates, well exposed along the Mokelumne River. In this section they are found to be irregularly layered, consisting of calcite and chlorite. A little quartz was noted, as also some clouds of magnetite dust. These rocks, therefore, represent metamorphosed calcareous tuffs. The breccias are frequently quartz-bearing, and are probably the ejectments of a dacitic magma. Their thickness is 1000 feet.

These are succeeded by quartz porphyry flows, which in turn are succeeded by schistose greenstone breccias. To the eastward heavy accumulations of auriferous gravels mantle the bedrock geology. Along the bluffs of the Mokelumne River and in the region north of the river the greenstone schists are literally charged with long angular fragments of an aphanitic quartz porphyry in which the quartz phenocrysts are small and infrequent.

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* W. Lindgren, Sacramento Folio.

† H. W. Turner, Jackson Folio.

The quartz porphyry flows are the copper bearing members. In the exposures along the river, especially on the north bank, the base of the quartz porphyry is found to interleave with the green glossy slate, and with coarse angular breccias. In the vicinity of the new shaft two main flows, separated by 300 feet of tuffs, are discriminable. A few hundred feet to the south they become confluent, but diverge almost immediately, becoming separated by a mass of greenstone schists whose coarsely pyroclastic character is still obviously patent.

The quartz porphyries have as a general rule been very thoroughly foliated, though some unsheared lenses have escaped metamorphism. The schistosity is occasionally crumpled and bent back on itself, and a slip-strain cleavage produced. The unsheared rock is remarkable on account of the abundance of large quartz phenocrysts, in a light flinty groundmass. In addition to the quartz, the microscope shows some porphyritic plagioclase (16°, maximum symmetrical extinction), orthoclase in nearly equal amount, and a few chlorite-epidote aggregates, which may possibly represent former ferromagnesian minerals. The groundmass is a microcrystalline aggregate of feldspar, part of which is striated, abundant chloritic matter in small flakes, and some magnetite. A few rather large grains of chalcocite were also noted. Mineralogically and structurally, the rock may be designated a quartz monzonite porphyry.*

The following is described as a type uncommon at Campo Seco. The rock is a dark colored quartz porphyry upon whose flow banding a rude foliation has been superimposed. Under the microscope is revealed an intricate fluidal structure characteristic of stiffly moving acid volcanics. Quartz phenocrysts are numerous, but bipyramidal forms are wanting. Certain minor flow bands consist of magnetite, while others are rendered opaque by magnetite dust. A few small magnetite phenocrysts are involved in the convolutions of the flow lines, much like the numerous larger quartzes. The flow bands are feebly polarizing mosaics, probably cryptocrystalline quartz and feldspar. Epidote grains are abundant in some, or yellowish chlorite in others, or both together in yet others.

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* W. Lindgren, Mon. 43, U. S. G. S., p. 81.

Numerous augen of glossy quartz in a highly schistose matrix of talcose appearance is the most characteristic feature of the sheared quartz porphyries. The schists from the mine workings are very light colored with a tinge of bluish green. Under the microscope the original bipyramidal character of the quartz is often recognizable. Many of the quartzes have been affected by a process which gives them a frayed appearance: short streamers of quartz have grown out from the main mass of the phenocryst parallel to the schistosity. The matrix consists of quartz and sericite intimately interwoven. Sections cut parallel to the schistosity show aggregate polarization of a scaly character. The interference tints are quite low (yellow to gray), which may be due to a compensatory effect of overlapping scales of finely foliated sericite. The talc-like mineral fails, however, to react for alkalies, but yields silica, alumina, and water at high temperatures. It appears probable that with the sericite a large amount of a hydrous aluminum silicate mineral is present.

The chalcopyrite present in the quartz porphyry schists has been sheared along with the other minerals, appearing now as a plating between the foliation planes. In this section it is seen to occur in long narrow streamers conforming to the schistosity, except where partially replacing quartz phenocrysts.

At the site of original location (malachite-azurite croppings) some barren lenses of vein quartz, 1 to 2 feet long, occur in the schists. Certain unschistified horses of quartz porphyry have escaped mineralization, but have undergone a profound metasomatic alteration. The original glassy quartzes of the quartz porphyry now appear as phenocrysts in a cryptocrystalline ground of silica. Under the microscope this ground is shown to be composed of fine granular quartz, portions of which assume a rude form of the "retiform structure" of Spurr. Some minute fibres of white mica can be detected under the highest power.

The large quartz phenocrysts (3mm) visible macroscopically, frequently show in thin section the smoothly rounded outlines characteristic of porphyritic quartz modified by magmatic corrosion. In one particular instance, however, the metasomatic alteration of the groundmass has also affected the phenocryst. In this case the quartz, which possesses a very nearly perfect hexagonal outline as indicated by a peripheral arrangement of inclusions, is surrounded by a narrow zone of secondary quartz in optical continuity with itself, but fading irregularly into the quartz of the groundmass.

The first-class ore at Campo Seco consists of chalcopyrite running about 8 to 10 per cent. zinc. The ore is often banded with black granular sphalerite. The gold content varies from one to three dollars; the silver values are about the same. In spite of the greater losses in the metallurgical treatment with high zinc content, it is found that the gold and silver values increase with the amount of zinc present.

The ore bodies are lenticular in shape, and attain a maximum thickness of 30 feet.

COPPEROPOLIS,* CALAVERAS COUNTY.

The meta-andesite belt attains a great thickness here, and displays in unusual perfection the evidence of its extrusive origin. Various amygdaloids, coarse breccias, and tuffs graduating into clay slates largely preponderate over the massive porphyries. In addition to the angular blocks of andesite, and at times fragmental quartz porphyry, the breccias are often thickly crowded with granitic material—hornblende gneiss, diorites, and hornblendites. The intimate association of the clay slates with the finer pyroclastics suggests a possible submarine origin for the entire series.† Dynamic movements have affected the region, shearing the massive volcanics but slightly, while often imposing a very thorough schistosity upon the finer tuffs, parallel to the bedding.

The Copperopolis Lode, which has been traced over a length of 10,000 feet, occupies a rather persistent horizon of clay slates, microcrystalline chlorite schists, and chlorite schists whose width approximates 100 feet. Within this zone, however, typical augite porphyrites and coarse breccias may occur, as the croppings at the Empire shaft show. The general strike is N. 60° W., and the dip 61° to the northeast.

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* J. D. Whitney, Geology of California, vol. I., pp. 254.
† A. Geikie, Textbook of Geology, vol. I., pp. 339.

Four thousand feet south of the Union shaft (the present hoisting shaft) is found a small gabbro boss, which from the nature of its inclusions, is determined to be intrusive in the greenstones of the footwall country. The gabbro consists essentially of abundant diallage, often altered to actinolite, and basic plagioclase feldspars, largely converted to aggregate of minute zoisite prisms. Toward the southern end of the boss a more basic modification of the gabbro is met with, which may descriptively be designated a feldspathic hornblendite. A similar rock occurs in small isolated croppings 200 feet southeast of the mill in the hanging wall of the lode, surrounded by schistose augite porphyries. The hornblendite here consists of numerous stout hornblende prisms bound together by a mesostasis of basic plagioclase feldspars which poikillitically enclose small perfect idiomorphic hornblendes. This hornblendite is cut by a system of quartzose biotite granite dykes. The main gabbro boss is intruded by thin albite dykes containing some faintly pink zoisite. At two points on the periphery of the gabbro, and on opposite sides of the boss, are lenses of serpentine, not exceeding 30 feet in thickness. Discrete areas of this serpentine, attaining a maximum width of 60 feet, appear intermittently along the footwall of the lode as far north as the Union shaft. It is occasionally altered to a talc schist. Along the footwall are also limited exposures of a deeply decayed rock of granitic habit, which fresher samples from the mine workings show to be a quartz monzonite. The greatest thickness exposed is 50 feet, and the northernmost cropping is 4000 feet north of the Union shaft, or about 8000 feet north of the gabbro boss. The mutual relations of the quartz monzonite and the serpentine were not discoverable. The quartz monzonite is intrusive into the chlorite schists of the lode, the actual contact showing a limited degree of fusion and assimilation over an inch or two. The quartz monzonite is composed of hornblende and biotite, both entirely chloritized, oligoclase, and orthoclase in equal amounts, and abundant quartz, with accessory apatite, zircon, and chalcopyrite, which by preference replaces the chlorite. The quartz monzonite shows evidence of severe movement and fracturing, and is often highly sulphuretted.

Another type of igneous rock is found in the hanging wall country just east of the mill. This is an aphanitic white rock, heavily pyritized, showing a few small glassy feldspars, which the microscope shows to be largely orthoclase. It may represent an offshoot from the quartz monzonite, which a prospect shaft shows is intrusive in the greenstones a hundred feet or so to the east.

Northward from the original location the Copperopolis Lode occupies the center of a broad strike valley; to the south, it forms the summit of a low, gentle ridge. At present the ores are being entirely hoisted from the northern portion of the lode, consisting of microcrystalline chlorite schists (locally known as "black pyritous slates"); in the southern portion the ore rock is thoroughly seamed with quartz stringers, which by their resistance to weathering, have elevated the lode above the surrounding topography.

The ore bodies consist of a series of lenses parallel to the foliation of the schists, about 200 feet long, 150 feet high, and 4 to 60 feet in width. They are not necessarily located in alignment, but frequently occur *en enchelon.* The shoots are stated to pitch 45° to the north in the plane of the dip.* The footwall is often defined by soft, putty-like talc, which has a tendency to run. There is no definite hanging wall, the ore shoots fading into barren rock, and the extent to which ore is stoped out is governed by the dictates of economic expediency.

Below the shallow zone of oxidation, 30 feet in depth, lie the unaltered sulphide masses. The ore consists of chalcopyrite, singularly free from admixture with other minerals, included in a fine-grained chlorite schist as gangue. The absence of the ordinary gangue minerals is so marked that ore containing quartz is retained as specimen material. The chalcopyrite occurs as thin bands, from an eighth to a quarter of an inch in thickness, ribboning the schist parallel to its foliation planes, though frequently anastomosing irregularly across the schistosity.

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* According to Mr. G. McM. Ross, Mgr., whose great courtesy it is the writer's pleasure to acknowledge.

The appearance of the typical ore is adequately expressed by its local designation: "black pyritous slate." From the slaty forms the transition to the chlorite schists is not great. Under the microscope the typical ore presents a uniform deep green color with little or no individualization of the chlorite into distinct flakes. Between crossed nicols a few rude shadowy crosses become apparent, and a general streaked effect, expressed in low blue gray colors, indicates the trend of the flow cleavage. The chalcopyrite is distributed in small stringers parallel to the cleavage, and is often accompanied by a fringe of epidote grains. Some of the large granules of chalcopyrite are associated with a little quartz and chalcedony. A very small amount of chalcocite was noted, some of which was peripheral upon the chalcopyrite. The quantity of secondary sulphide, however, is nearly insignificant.

The chlorite schist ore differs from the preceding only in the fact that the chlorite is in well-developed plates, many of which show evidence of internal movements. Some grains of titanite occur.

Ore rock taken from near the footwall of Level 4 shows a few additional features. In sections cut normal to the schistosity the rock is seen to be composed almost exclusively of chlorite, often in minute spherulites, and a few "porphyritic" plates of clinochlore. The discrimination, clinochlore, is made on account of its superior birefringence and deeper pleochroism. In certain plates chalcocite can be seen replacing the clinochlore parallel to the cleavage lines. The amount, however, is inconsiderable. A few rectangular sections of andalusite occur. Grains of titanite, sometimes partially idiomorphic, are rather abundant. Splendid rutile prisms, surrounded by strongly pleochroic halos of deep olive green color, constitute a characteristic feature of this variety of chlorite schist.

The andalusite may indicate contact metamorphism by the quartz monzonite intrusive, and lends weight to the probability suggested by the petrographic and stratigraphic data that the Copperopolis chlorite schists represent argillaceous andesite tuffs dynamically metamorphosed.

Since the deposition of the ore much movement has taken place, shearing the chalcopyrite and plating the foliation planes of the chlorite schist with yellow mineral.

The introduction of the ore has been subsequent to the latest intrusive, for the quartz monzonite is often impregnated with chalcopyrite, especially along fracture zones. The amygdules of the flows west of Copperopolis occasionally show a speck of chalcopyrite in the interior of the solid filling.

NAPOLEON MINE, CALAVERAS COUNTY.

The Napoleon mine is six miles southwest of Copperopolis. The section between them is composed largely of the meta-andesites, including, however, about 5000 feet of Upper Jurassic clay slates and an intrusive mass of granodiorite.

The prevailing rock in the vicinity of the Napoleon mine is a massive quartz porphyry whose characteristic feature is its abundance of glassy quartzes in an aphanitic base of flinty appearance. The microscopic petrography of this rock shows numerous idiomorphic quartz phenocrysts, often affected by magmatic corrosion, and a large number of porphyritic feldspars, untwinned, turbid, opaque, and frequently containing much secondary epidote. Femic constituents were nearly absent, and are now represented by chlorite. The groundmass is a microcrystalline assemblage of feldspar, quartz and minute spherulites.

Two thousand feet east of the shaft the tuffs, breccias, amygdaloids, and porphyries of the meta-andesite series appear in great thickness. In the immediate vicinity of the mine is an intercalated flow of hornblende andesite, which having a thickness of about a hundred feet at the hoisting shaft, rapidly thickens towards the southeast to 500 feet. The distinguishing features of this rock are the presence of hornblende prisms and the great abundance of calcite amygdules. Certain highly feldspathic facies are associated with the hornblende andesite. The quartz porphyry where resting upon the andesite was found to show a narrow chilled selvage against a scoriaceous amygdaloid.

The lode lies along the contact of the feathering end of the andesite flow with the quartz porphyry. This contact has been a locus of exceptional dynamic activity, along which the hornblende andesite has been reduced to a chlorite schist, and the quartz porphyry has been brecciated, and more rarely, converted to a sericitic quartz porphyry schist. The width of this shear zone is about 30 feet, though within this belt there are horses of unschistified rock. The lode strikes N. 75° W., dip 62° S. The hanging wall is quartz porphyry and is fairly regular; the foot is the meta-andesite, is soft and rotten, and more irregular.

The ore is solid chalcopyrite, massively schistose and often roughly banded with ruby zinc. Calcite and some galena are occasionally noted. The unschistified lenses of rock noted in the croppings form horses of second-class ore, 6 inches to 2 feet in diameter and several feet long. They are more poorly mineralized, and contain a larger proportion of iron pyrites. Where cubes of pyrite have developed in the vicinity of the calcite amygdules of the hornblende andesite, they fail to replace the carbonate, but remain imperfect and have grown around it.

RESUMÉ.

The Foothill copper belt lies west of the main gold-producing region, and includes a series of copper deposits occupying the lower foothills of the range. Great stress cannot be laid on the unity of this belt as a metallographic province, inasmuch as two typical occurrences, notably Pine Hill and Valley View, were long worked as gold mines, until deeper exploration revealed the unsuspected presence of copper. Along this belt are also the gold mines of Ophir, described by Lindgren.* Copperopolis and Napoleon are held to be on separate branches of the copper belt. Between them is a great thickness of black clay slates, upon which is located the Royal, a large gold-quartz mine (120 stamps).

The copper deposits are, however, all closely associated with the meta-andesites, and belong to the general type of replacement deposits along shear zones. This gives a certain geologic unity to the entire belt. The replacement has been equally thorough in very diverse rocks, producing the large ore bodies of Copperopolis in chlorite schists, and the extensive, and more massive, ore bodies of Campo Seco in quartz porphyry schists.

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* W. Lindgren, 14th Ann. Rept., U. S. G. S.

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Vol. 4, No. 18, pp. 425-430 ANDREW C. LAWSON, Editor

AN ALTERATION OF COAST RANGE SERPENTINE.

BY

A. KNOPF.

In the vicinity of North Berkeley bold massive croppings of a curiously weathering rusty red rock form conspicuous features of the foothill slopes. They frequently attain a height of 40 or 50 feet, and owing to the striking character of their superficial alteration, readily attract attention. Under the action of the weather they yield cavernous, honeycombed masses of great variety of form, gnarled and twisted, and often of fantastic fashioning.

The unweathered facies of this rock consists of an aggregate of chalcedony and rhombohedral carbonates, whose relative proportions may vary within rather wide limits. Highly siliceous phases are common, while the other extreme is represented by phases indistinguishable from crystalline limestones. In the typical rock, however, the carbonates are dominant, and the chalcedony subordinate. The structure is often peculiar and characteristic, and is due to the intimate lenticular interlamination of the two main constituents. On a fresh fracture the rock is colored a sort of terra-cotta red, and is seamed with small vitreous quartz veinlets, and bunches and veins of white waxy chalcedony. Chromite occurs in numerous small specks, and upon isolation gives a good chromium reaction with borax. Occasionally a deep green mineral of lamellar habit can be found. Cleavage flakes show the emergence of a negative acute bisectrix of small axial angle. The extinction is parallel to a well-defined cleavage, the relief low, and the birefringence feeble. These properties, together with a fibrous habit, unquestionably identify the mineral as bastite. The presence of chrome micas was suspected, but could not be verified.

The rocks under discussion have an extensive distribution in the hills north of Berkeley, occurring as lenticular masses in the Franciscan sandstone. The invariable presence of glaucophane schists is suggestive. They occur at numerous other points throughout the Coast Ranges, and are locally known as "the quicksilver rock," on account of their frequent association with cinnabar deposits. They were described as forming a subordinate member of the Franciscan series (lowermost Cretaceous?), and were provisionally designated as a silica-carbonate sinter.[*] This was attacked by Fairbanks,[†] and in particular the suggestion that the formation might be used in correlating isolated portions of the Franciscan. His contention was based on the fact that the rock occurs as the gangue of the quicksilver ores which are known to be of post-Miocene age, and that the silica-carbonate sinter may, therefore, occur at any stratigraphic horizon.

Becker,[‡] however, seems in part to have recognized the derivative origin of the rock under consideration, but his views are largely obscured by his conceptions of the metamorphic character of the Coast Range serpentines. Von Groddeck,[‖] in a remarkable paper on the Quicksilver Deposits at Avala, Servia, was the first to draw attention to the pseudomorphic character of the ore rock at New Almaden.

His conclusions, both as to the Servian and California occurrences, were vigorously denied by Becker.

The recent finding near North Berkeley of some exceptional material allows the origin of the carbonate rock to be fixed beyond question.

Under the microscope a thin section of typical carbonate rock is seen to consist of an intimate mixture of lime-magnesia carbonates and chalcedony. The carbonates are without crystalline boundaries and are frequently stained with yellow iron oxides. The unusually strong differences of relief for O and E indicate magnesian carbonates, and in exceptional cases even siderite. The chalcedony is composed of aggregates of beautifully formed minute spherulites. Granular and automorphic magnetite, and grains of chromite occur as accessories. The chalcedony commonly occupies small lenticular areas surrounded by narrow bands of carbonate, and the structure produced thereby is characteristic of the silica-carbonate rock.

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[*] A. C. Lawson, 15th Ann. Rept. U.S.G.S., pp. 435.

[†] H. W. Fairbanks, Jour. Geol. V. 63–67, 1897.

[‡] Monograph XIII. U.S.G.S.

[‖] Zeit. für Berg, Hutten-u-Salinenwesen, vol. 33.

At North Berkeley this type is found grading into a rock whose characteristic feature is the abundance of lamellar pyroxenes of decidedly bronzy metallic lustre. Veinlets of chrysotile under a millimeter in thickness form a reticulate network traversing the rock.

In thin section large plates of orthorhombic pyroxene become apparent. Their color is brownish yellow, and the deeper colored sections show a faint pleochroism. A strongly colored plate was found to give a decided pleochroism: green parallel to *c* and yellowish green transverse to *c*. The pyroxene is therefore, bronzite. Small grains of chromite are included in the bronzite.

The pyroxenes are partially serpentinized and the remaining bronzite plates represent the survivors of the process of serpentinization. Even these show strong variations in the degree of relief, varying from the characteristic high relief of the pyroxenes down to that of Canada balsam. The latter probably represent the bastite modification, though the position of the optic axial plane could not be tested. The pyroxenes are, moreover, traversed by a ramifying system of carbonate fibres. Certain banded veins of serpentine which intersect the slide are found not merely cut across by the carbonate, but show also a progressive replacement by means of numerous small apophysal tongues. These paragenetic relations show that the carbonate is epigene upon the serpentine, and not merely a residual product of the process of serpentinization.

In certain sections the carbonate can be seen replacing the pyroxene directly without the intervention of the serpentine stage. The advancement of carbonatization appears easiest in the direction of the vertical axis.

Often a sort of net structure is produced by capillaries of carbonate encircling areas of serpentine. From these, gradations can be traced wherein the carbonate has completely supplanted the serpentine. It is not unusual to see the characteristic antigorite structure displayed by carbonate.

Certain larger veinlets of carbonate also occur, and usually show a well-developed rhombohedral cleavage. The usual strong differences of relief are displayed, and from the very high index for O, dolomite and magnesite are suggested.

The remaining portions of the sections are composed of confused aggregates of serpentine, which render inferences as to their derivative origin unsafe. Only occasionally is the characteristic antigorite structure visible. No olivine, or structure certainly referable to its former presence, could be found. A few mosaic polarizing veinlets of quartz seam the slides.

Under medium high power some tangled trichite-like aggregates can be discerned embedded in the carbonate and quartz. They possess a metallic lustre, inclining to brassy. A straight and relatively stout prism showed a hexagonal cross-section. These characteristics serve to identify the mineral as millerite.

Summarizing the petrographic details, we find that the rock is composed of allotriomorphic plates of bronzite, often serpentinized, and magnesian carbonates epigene upon both the serpentine and the pyroxene. It, therefore, conforms to a partially altered pyroxenite.

From the rock at North Berkeley whose origin is thus apparent, the series of changes involving the transformation to the carbonate rock may readily be followed, and may even be seen in the hand-specimen whose typical pyroxenite character is macroscopically obvious. Throughout the Coast Ranges, however, the carbonate rock often occurs in isolated croppings, highly weathered, or associated with serpentine in obscure relations, hence the uncertainty which has existed as to its origin.

The approximate chemical composition of the original unaltered bronzitite as computed from the mineralogical content is:

$$
\begin{aligned}
\mathrm{SiO_2} &= 60 \\
\left.\begin{array}{r}\mathrm{Fe_2O_3} \\ \mathrm{Al_2O_3}\end{array}\right\} &= 6\text{–}8 \\
\mathrm{MgO} &= 28\text{–}30 \\
\mathrm{CaO} &= 2 \\
\hline
\mathrm{Sum} &= 100\%
\end{aligned}
$$

Analysis of the silica-carbonate rock (excluding macroscopic quartz veinlets) yielded the following result after digestion in hydrochloric acid:

Insol. residue = 16.24% (96.4% SiO_2)
$\left.\begin{matrix}Fe_2O_3\\Al_2O_3\end{matrix}\right\} = 5.26$
$CaO = 13.20$
$MgO = 25.89$
Theoret. % CO_2 = 38.61
Total $H_2O = 1.15$
Sum = 100%

The analysis represents the end product of two successive processes: first, serpentinization, and secondly, dehydration and carbonatization. The former involved a large increase of volume, the latter a decrease. This latter process has been attended by the formation of vitreous quartz veinlets, whose frequent comb-in-comb structure indicate their deposition in open fractures. The above analysis when compared with the composition of the bronzitite shows several noteworthy features. An exact discussion is not possible on account of the uncertainty of the volumetric relations involved, but the following points appear well established: that there has been a large expulsion of silica by carbonic acid; that a notable enrichment of lime has taken place; and that the magnesia and total sesquioxides (largely iron) have practically remained constant.

It has already been pointed out that in thin section the silica-carbonate rock often presents a highly unique and characteristic structure, due to an anastomosing system of carbonate capillaries enclosing discrete eye-like areas. These small lenticular areas are composed of allotriomorphic carbonate, or spherulitic chalcedony, or both together.

The carbonate veinules possess a fibrous structure, the fibres not being continuous across, but growing from both walls toward the center. The center line is occupied by yellow iron oxide, which frequently extends in between the carbonate fibres, thus producing a sort of stiff, orthogonal dendritic structure. The above phenomena represent a pseudomorphic replacement of a schistose serpentine, the carbonate capillaries occupying the foliation partings produced by movement consequent upon volume expansion during hydration.

The production of the silica-carbonate rock, then, illustrates an extensive case of hydro-metamorphism, effected by solutions highly charged with carbon dioxide, and carrying calcium carbonate and metallic sulphides.

University of California,
May, 1906.

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THE GEOMORPHOGENY
OF THE
TEHACHAPI VALLEY SYSTEM.

BY

ANDREW C. LAWSON.

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INTRODUCTION.

At the southern end of the Sierra Nevada there are certain high valleys, situated about 4000 feet above sea level, which, by reason of their abnormal position, their peculiar drainage, their large dimensions, and their discordant relation to their geomorphic environment, invite geological inquiry as to their genesis.

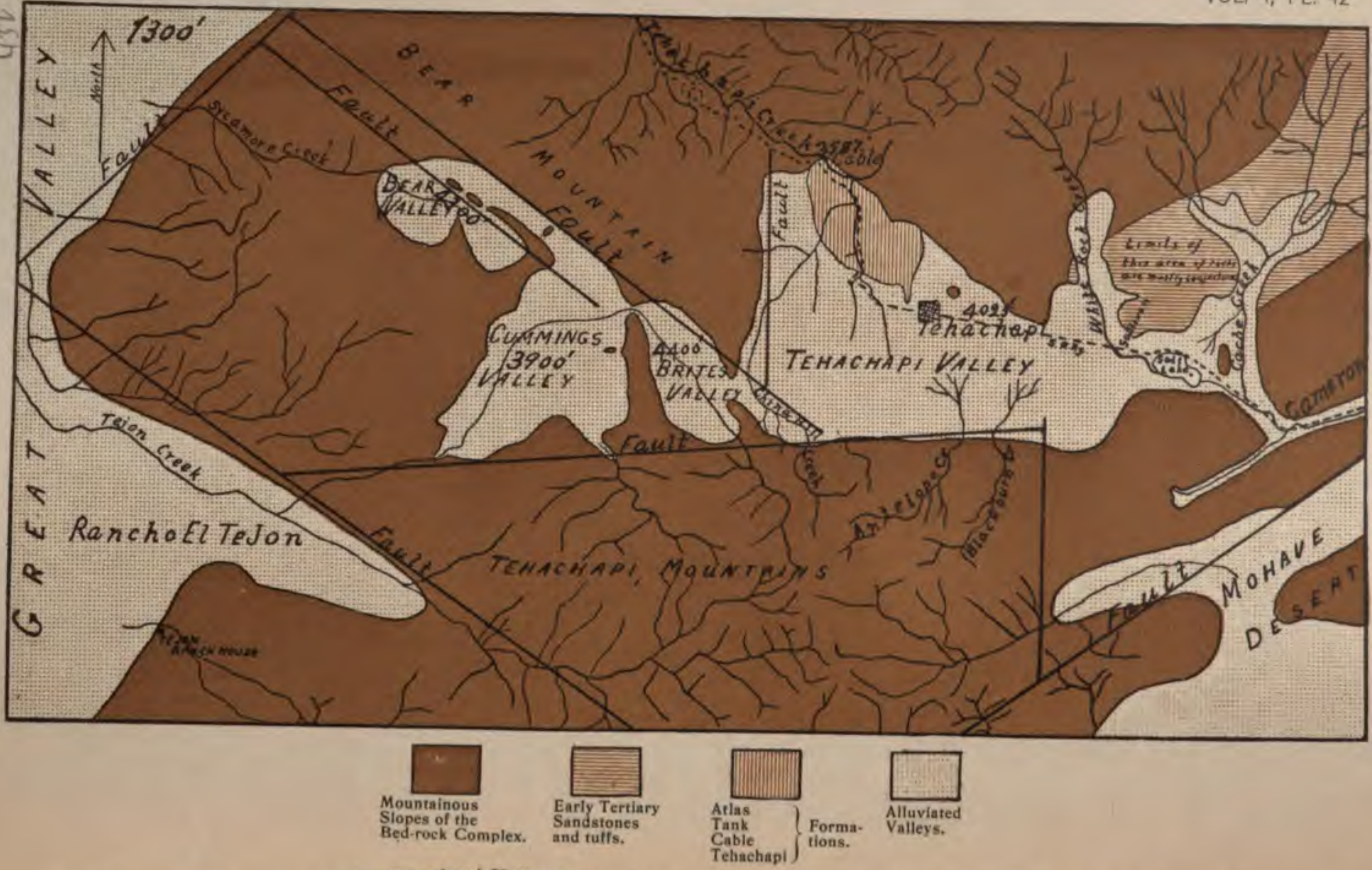
The largest of these valleys is Tehachapi, and, as it forms the pass over the mountains for the railways connecting the Great Valley with Southern California, it was the first to attract the attention of the writer. An attempt to get familiar with its features led to the discovery, however, that it was but one of a system of similar valleys which characterize the region. In the country to the west of Tehachapi lie Brites Valley, Cummings Valley, and Bear Valley. It is the purpose of this paper to give a brief descriptive account of these valleys, to indicate something of their geological history and in so doing suggest at least a partial explanation of their rather unique features.

TEHACHAPI VALLEY.

General Features.—Tehachapi Valley is situated on the summit of that portion of the Sierra Nevada which lies between the southern end of the Great Valley and the Mohave Desert. Its extent from east to west is about 12 miles. Its breadth in its middle part, at the town of Tehachapi, is about 4½ miles. At its west end it is 6 miles wide and at its extreme east end it narrows to about half a mile. It has thus in ground plan the form of a right angled triangle, the right angle being at the southwest corner of the valley. Its area is about 36 square miles.

The boundaries of the valley are for the most part bold mountain slopes, which rise to crests at no great distance from the valley. The area of the hydrographic basin in which the valley lies is about 130 square miles. From this statement it will be apparent that the streams which flow into the valley from the surrounding mountains are small. The annual rainfall is 10½ inches.

Streams.—Of these streams the two largest are on the north side of the valley toward its east end, and are known as Cache Creek and White Rock Creek. Both of these enter Tehachapi Valley through trumpet-shaped side valleys, which in their stage of geomorphic advancement and in their degree of alluviation are seemingly homologous to, and harmonious with, the main valley to which they are tributary. These tributary valleys are of the nature of embayments in the mountains on the south, and,



Physiographic Sketch Map of the Tehachapi Valley System showing their relation to the Great Valley and to the Mohave Desert.

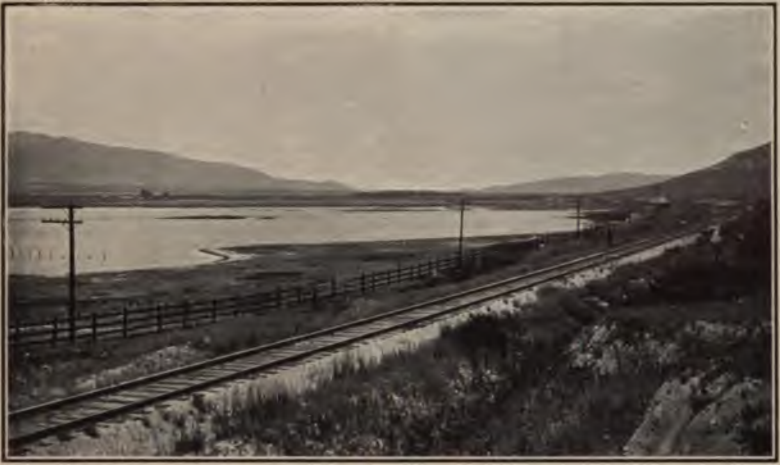
Scale: 1 inch = 4 miles.

as their floors are accordant with the floor of the main valley, they cause the ground plan of Tehachapi Valley to have in this part a distinctly indentate contour. There are three notable streams entering the valley from the high sharp mountain ridge which forms the southern boundary of the valley in its western part. These are from west to east, China Hill Creek, Antelope Creek, and Blackburn Creek. These three creeks are in marked contrast to Cache Creek and White Rock Creek on the south side. They emerge upon Tehachapi Valley through narrow rocky gorges, whose bottoms are not yet cut down to the level of the main valley floor, and the alluvial fans which they have built up apex wholly outside of the mountain pass, within the confines of the valley. These cañons are so narrow that they effect no appreciable indentures in the ground plan of the valley boundaries, and the mountain front is here remarkably even and straight, as well as steep.

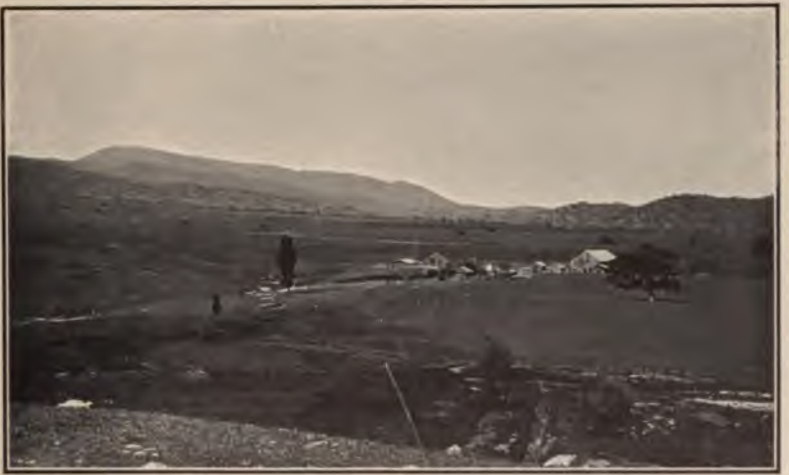
Alluviation.—The floor of Tehachapi Valley is for the most part a surface of alluviation, and appears to the cursory glance uniformly flat. Unfortunately the region has not yet been topographically mapped and we have, therefore, no exact measure of the slopes of this apparently flat floor except such as are afforded by the railway levels. The altitude at Tehachapi station is 3963 feet; at the summit, 2 miles to the east, it is 4025 feet; and at Sullivan's, 3½ miles from Tehachapi, it is 3980 feet. These figures give the altitude of the central part of the valley along its north side, which is the lower side. From the line of the railway the floor of the valley slopes up to the south on the surface of the confluent alluvial fans of China Hill, Antelope and Blackburn Creeks. In the eastern part of the valley, on the contrary, the alluvial fans of White Rock and Cache Creeks from the north dominate the slope of the valley and cause its lower part to be on the south side.

Between the alluvial fans of these two creeks there is on the south side of the railway a saline lake, the expanse of which varies with the season, but which at its largest is less than a square mile in area. This lake receives the waters of White Rock Creek. The waters of Cache Creek are sometimes shed down the west side of its fan to the lake and at other times to the east side out through the rocky gorge at Cameron to the Mohave Desert, the position of the stream upon its fan being unstable and fluctuating. Usually the lake has no outlet and the waters are strongly saline. It is said that deposits of salts have been worked in the clays which underlie the lake to a depth of 8 feet. Occasionally, however, the lake appears to overflow around the lower edge of the Cache Creek fan into the gorge leading out to Mohave.

The depth of the alluvial infilling of the valley is not known. Certain wells that have bene sunk indicate that it is by no means a shallow veneer. A well sunk for water on the railway about three-quarters of a mile above Cameron at the extreme east end of the valley passed through 125 feet of alluvial gravel, sand, and clay without reaching solid rock. On Spencer's ranch a well was sunk for water on the northwest quarter of Section 34, Tp. 32 S., R. 33 E. This well is said by the driller to have passed through 10 feet of black clayey loam, then 125 feet of yellow clay with fine gravel, and then through 30 feet of gravel with coarse boulders at the bottom up to 10 inches in diameter. At this depth no water was found and for practical reasons the well was abandoned. Another well was sunk in the immediate neighborhood, to a depth of 344 feet through gravelly sandy and clayey alluvium, water being found at a depth of 248 feet and rising in the well to within 120 feet of the surface. In this well very few pebbles were found larger than one's fist and only rarely was a boulder found as large as a man's head. The writer visited the well and examined the material that had been taken from it. The well is situated less than a mile north of the base of the steep mountain slope which bounds the valley on the south. We have thus in the record of this well evidence that the alluviation of the valley reaches a depth of not less than 344 feet. Several wells have been sunk in the town of Tehachapi, and these are said to yield water first at a depth of 35 feet and again at about 90 feet below the surface. One well, however, is said to have been sunk to a depth of 166 feet, mostly in clayey alluvium with gravel at the bottom. The alluvial floor of the valley is in part suitable for cultivation, and the greater part of it is fenced for ranch purposes, but there are probably



A. Looking west across Tehachapi Valley from the east end. Saline lake in the foreground.



B. Southwest corner of Tehachapi Valley. Looking southwest toward the barrier which separates Tehachapi and Brites Valleys across the alluvial cone of China Hill Creek.

not more than a dozen ranchers actually engaged in the cultivation of the soil. Portions of it are, however, utilized as cattle ranges.

Another indication of the volume of alluvium in the valley is afforded by the dissection of the alluvial cone of Antelope Creek at its apex. Here Antelope Creek has greatly deepened its rocky gorge within the mountains since the apex of the alluvial cone was established, and this deepening of the gorge has necessitated the dissection of the cone. The extension of the gorge through the apex of the fan reveals a section of alluvium 250 feet thick above the stream. In the vicinity of the apex of the China Hill alluvial cone a much greater thickness may be inferred. Here the coarse gravels of the upper part of the cone have been hydraulicked for placer gold.

Isolated Hills.—An interesting feature of the valley floor is the occurrence of certain isolated rocky hills which project as island-like masses through the alluvium. There are two such hills of prominence, both on the north side of the valley and both composed of the granitic rocks of the surrounding mountains. One of these lies to the northeast of Tehachapi and less than a mile distant from the town. It rises to an altitude of perhaps 100 feet above the surrounding plain as a rugged more or less conical mass of bare rock. The other is at the east end of the valley and lies at its confluence with the wide-gaping tributary valley of Cache Creek. It is surrounded by the alluvial fan of that creek, the stream, which is now to the east of the hill, having formerly flowed to the west. The hill is about half a mile in length from north to south and about half as wide at its base and it is probably not less than 200 feet high, its bare rocky precipitous slopes being in striking contrast to the surrounding alluvial plain. The isolation of these hills from the neighboring mountain slopes affords additional suggestion as to the great depth of the alluvial infilling of the valley, and indicates something of the irregularity of the rock surface upon which the alluvium, in parts of the valley at least, rests. The best actual exposure of alluvium of the valley floor which came under the writer's observation was that afforded by a trench at the extreme eastern end of the valley at from one-half to three-quarters of a mile above Cameron station. The trench is a new feature of the topography and was cut by the exceptionally heavy run-off due to the rains of the winter of 1904-5. The trench is 13 feet deep below the floor of the valley. In the bottom of the trench there is exposed a dark gray or drab-colored, stiff clay with remains of plant stems in it, to a thickness of 3 feet. Upon this clay with a sharp horizontal contact rests 10 feet of the ordinary alluvium of the valley, consisting of light colored granite sands with lenses of gravel. The contrast of this sandy and gravelly alluvium with the underlying stiff clay is significant of a change in the conditions of deposition. This contrast is the more significant when it is stated that the exposure occurs in the narrowest part of the valley, practically in its outlet to Mohave, the width of the floor here being only 200 yards, between steep rocky walls. It would be interesting to know the thickness of the clay, but unfortunately this could not be ascertained.

Remains of Mammoth.—About a mile and a quarter to the westward of Tehachapi station on the line of the railway, certain trenches were cut by the Southern Pacific Railway Company for the purpose of developing a supply of water for one of their tanks. In this work a large bone was found and was forwarded to the University of California by Mr. de Heur, the resident engineer of the company at Bakersfield. The bone has been identified by Professor J. C. Merriam as the tibia of a mammoth.* The writer subsequently visited the locality under the guidance of one of the workmen who was present when the bone was found. The trench is now boxed in, but enough of the section was seen to establish the fact that it cut through about eight feet of black adobe clay, then through three feet of yellow clay. This yellow clay rests upon gravelly alluvium, the rock fragments of which are angular and little water worn, and range in size from minute fragments with sand up to pieces the size of one's fist. The depth of this gravelly alluvium is not revealed. The mammoth bone was found at a depth of between 11 and 12 feet, or just below the yellow clay. The yellow clay and the gravelly alluvium represent with little question the lower edge of the China Hill Creek cone. But the black adobe clay is the product of more recent accumulation, under marshy conditions, due to springs, on the narrow flood plain of the modern creek where it has trenched the cone.

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* This is now in the Collection of Vertebrate Palaeontology, Univ. Calif. Accession No. 9842.

Rocks of the Surrounding Mountains.—The prevailing rocks of the mountains which encircle Tehachapi Valley, as well as the other valleys to the west of it which are described in this paper, are those of the Bed-rock Complex of the Sierra Nevada. They comprise a series of metamorphic rocks, represented chiefly by crystalline limestones and mica schists with quartzites, and various plutonic irruptives of granitic habit which have invaded the metamorphic series. The limestones occur in isolated patches in numerous localities and appear for the most part to be large inclusions which sank down into the granite when the latter was viscous. The mica schists occur in more persistent belts of no great width. Both limestones and schists have a persistent north and south strike with easterly dip at angles of from 45° to 60°, though sometimes vertical. The granitic rocks, however, greatly preponderate throughout the region, and constitute the great bulk of the mountains. The limestone is quarried at a number of localities, but most extensively at the mouth of Antelope Cañon to the south of the town of Tehachapi where it is burnt for lime.

The superjacent series of the northern portion of the Sierra Nevada is represented in this region by two formations of stratified rocks, which rest unconformably upon the Bed-rock Complex. The lower of these is well exposed in the middle and upper parts of the tributary valley of Cache Creek. It consists of a great volume of coarse arkose sandstones and conglomerates with some thin beds of sandy shale. On the northwest side of the middle part of Cache Creek they dip at an angle of 60° to the southeast, and their superposition upon the granite is well exposed. On the east side of Cache Creek these sandstones appear to dip to the northwest and to strike to the northeast, curving around the granite traversed by the creek in its lower part. In certain of the shale beds referred to there are abundant fossil leaves in a good state of preservation, and their occurrence here renders it probable that the formation is a fresh-water deposit. The age of the beds is not known but it is probable that they are early Tertiary. The second formation of stratified rocks is well exposed in the vicinity of Sullivan's station and thence up White Rock Creek. It is probably stratigraphically above the sandstone and conglomerate formation of Cache Creek but this was not certainly determined. The formation is almost wholly made up of regularly stratified volcanic tuffs and agglomerates, well cemented, but there are with these near Sullivan's station some beds of greenish gray sandstone which may be composed only in part of volcanic ash. These stratified tuffs and agglomerates lie in a well marked syncline, the axis of which pitches to the northeast. The formation lies chiefly in the country between White Rock Creek and Cache Creek, but the nose of the syncline above referred to crosses White Rock Creek, toward the west, and in this direction one passes in a few hundred yards from the tuffs to the underlying rocks of the Bed-rock Complex. The dip of the strata on the southern limb of the syncline, near Sullivan's, is from 25° to 30°.

The most interesting feature of these superjacent formations is their degree of deformation, and the evidence that they thus afford that orogenic movements have occurred in the southern end of the Sierra Nevada which seem not to have affected the same series in the middle and northern part of the range. That is to say, while the superjacent series in middle and northern California have been profoundly faulted by the movements which gave rise to the Sierra Nevada tilted block, there appears to have been no folding of such rocks; while here on the north side of the east end of Tehachapi Valley the evidence of flexure is marked.

Outlets of Tehachapi Valley.—Perhaps the most remarkable feature of Tehachapi Valley is the fact that it has two outlets. Both of these are incisive stream gorges cut in the granite rocks of the Bed-rock Complex. One drains the western portion of the valley to the Great Valley and is occupied by Tehachapi Creek which leaves the valley at its northwest corner. The other drains the eastern part of the valley to Mohave Desert. The Tehachapi Creek gorge has a higher grade than that leading out to Mohave, carries more water and is more sharply cut. The cañon draining out to Mohave is wider in its bottom, carries little water except during heavy rains, and in its upper part is encumbered with stream gravels and sands. In its lower part, however, the grade becomes too steep for this stream drift to linger on the cañon floor and the stream runs on bed rock. On the whole, the Mohave outlet of the valley presents a more mature aspect than the gorge of Tehachapi Valley. The divide between these two drainages lies in the nearly flat, expansive, alluviated floor of Tehachapi Valley near its middle part. The explanation of this anomalous drainage must be deferred till certain other features of the geology of the valley are presented.

Although the fossil leaves of the sandstones and shales of Cache Creek indicate that they were laid down in a fresh-water basin, it is not supposed that this basin had any structural relation to the present Tehachapi Valley. The Cache Creek beds are apparently much more extensive to the northeast than the limits of the valley in that direction. Cache Creek Valley, moreover, is a valley of erosion cut in part out of the sandstone formation. As will be seen later there is ground for believing that Cache Creek Valley, as a geomorphic feature, probably antedates the main Tehachapi Valley. The tuffs and agglomerates of White Rock Creek are probably of about the same age as the sandstones and were doubtless laid down in the same basin.

In the northwest corner of Techachapi Valley, however, there is a group of formations which seem to have a somewhat more intimate relation, as regards their basin of accumulation, with the present Tehachapi Valley. These formations will be first listed in the order of age and their characters and relationships will then be briefly reviewed:

1. An Ancient Alluvium, here designated the *Atlas Formation.*
2. Andesitic lava flows and tuffs, here designated the *Tank Volcanics.*
3. Fresh-water lake beds, here designated the *Cable Formation.*
4. Post-lacustrine alluvium, here designated the *Tehachapi Formation.*

Atlas Formation.—This formation is known from three exposures, one at the nose of the ridge one mile west of Tehachapi station on the north side of and immediately adjacent to the railway; another in the cut one-eighth of a mile below Cable, just north of the steel bridge; and the third in the bottoms of certain cañons tributary to Tehachapi Creek on the east side of the railway and about midway between Cable and Tehachapi stations. In all three of these exposures the formation has the same characters and the same stratigraphic position. It is made up of angular fragments of rocks of the Bed-rock Complex including schists, quartz-diorite, granite, etc., pieces of quartz and considerable granite sand or arkose. The fragments are frequently from 6 to 12 inches in diameter but are prevailingly less than 6 inches across. This aggregate presents the normal characters of a typical alluvium, such as is deposited at the mouth of a high grade, short mountain stream. This alluvial debris has been well cemented; but since its cementation it has been thoroughly decomposed, so that the blocks and smaller fragments of the crystalline rocks are now soft and incoherent and crumble under the pressure of the fingers. Independently of the stratigraphic position of this formation, it is easily recognized and distinguished from other alluvial accumulations of the region by these two characters: viz: its cementation and its decayed condition. In the railway cut one-eighth of a mile below Cable, near where one enters the rocky Tehachapi cañon, there are exposed 12 feet of this formation. Above it and resting stratigraphically upon it are 3 feet of yellowish white volcanic tuff; and above this there is a thick sheet of andesitic lava. There is no doubt, therefore, that the alluvium antedates the only volcanic rocks that are known in the region.

The same relations are revealed in the cañons east of the railway between Cable and Tehachapi. Here the streams have cut down through stratified tuffs into the Atlas Alluvium which is thus revealed to a thickness of perhaps 30 feet.

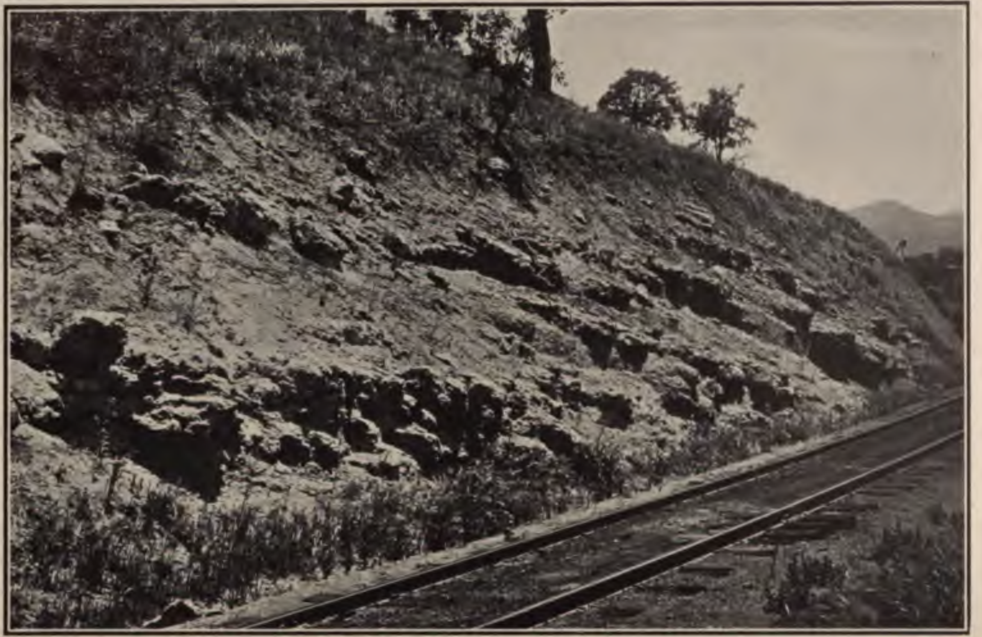
The thickest exposure of the formation is the first one mentioned at a point about a mile west of Tehachapi station. Here there are about 50 feet of the formation shown in the railway cut and in the adjacent steep slopes. A little beyond this point on the railway grade there is exposed an area of 20 or 30 acres of andesitic lava which probably overlies the decomposed alluvium. The entire absence of fragments of lava in the alluvium, although carefully looked for, is in accord with this interpretation which is, however, based on independent structural evidence.

Tank Volcanics.—These rocks are best exposed in the vicinity of the railway tank which is situated about 2 miles below Tehachapi station on Tehachapi Creek. The lava is exposed over an area of 20 or 30 acres with a slope of 5° to the west and a vertical range of about 150 feet. Its relations here are not as well revealed as in other localities, but it appears to rest in part upon the Atlas Alluvium mentioned above, and is certainly below the Tehachapi formation. The Cable formation is not here exposed.

Another occurrence of the lava is on the west side of Tehachapi Creek to the west of the high ridge, composed of the Cable and Tehachapi formations, which is situated southwest of Cable station. Here the lava rests upon an old surface of the Bed-rock Complex composed of granitic rocks, schists and crystalline limestone and is clearly stratigraphically below the easterly dipping beds of the Cable and Tehachapi formations. A third occurrence has already been mentioned in speaking of the exposure of the Atlas Alluvium below Cable. Here it was stated that the Atlas Alluvium was overlain by a bed of yellow tuff and a thick sheet of andesitic lava. The same section shows very clearly the superposition of the Cable lake beds upon the sheet of andesite.

The tuffs and agglomerates which lie upon the Atlas Alluvium in the country between Cable and Tehachapi station are without question to be correlated with the lava as part of the same volcanic extravasation. These volcanics as has been shown are clearly above the Atlas Alluvium; but they are no less clearly below the Cable lake beds which are well exposed by the same dissection as that which has revealed the underlying beds.

Cable Formation.—The rocks of this formation are best exposed in the vicinity of Cable station on both sides of the cañon of Tehachapi Creek. They comprise limestones, cherts, gravels, clays, and fine light colored volcanic tuff. These rocks are for the most part well stratified and have a thickness which is estimated at about 250 feet. Where the base is exposed, the formation rests in some places upon the Tank Andesite, as on the west side of Tehachapi Creek below Cable, in some places on a coarse agglomerate made up of andesitic fragments, and in other exposures directly upon the rocks of the Bed-rock Complex. In every case where it is exposed it is overlain by the alluvium of the Tehachapi formation. The limestones are cherty and contain fresh-water molluscan remains such as species of *Planorbis* and *Physa* in a good state of preservation. The clays are more or less admixed with fine volcanic ash and in such beds there are often remains of roots and stems which have been thoroughly silicified. Not only are the limestones cherty but they pass along the strike into beds which are composed almost wholly of evenly stratified light colored to white cherts. These cherts outcrop rather boldly and as they occur near the base of the series they facilitate the delimitation of the area of the formation. The pebble beds are not more than a few feet thick and are composed of smoothly rounded pebbles of small size. These beds of course indicate shallow water conditions and proximity to the shore line of the lake. The occurrence of volcanic ashes in the clays and as distinct beds may indicate a survival into the lacustral period of the volcanic activity, which gave rise to the pre-lacustral and underlying Tank Volcanics; but it may also be explained as due to the erosion of these earlier volcanic deposits. To the east of Tehachapi Creek these fresh-water beds strike southeast from Cable and dip southwest beneath the overlying Tehachapi alluvium at angles varying from 12° to 20°, for a distance of nearly 3 miles, beyond which the outcrop can no longer be followed with certainty. The strike at the point where the outcrop ends probably swings around to south and follows the lower east flank of the ridge extending toward Tehachapi station. To the west of the creek below Cable they dip southerly and thence going south the strike swings around to north and south with an easterly dip and at a point about a mile north of Cable station the dip of the beds is vertical. About three-quarters of a mile southwest of Tehachapi station near the cemetery there is an outcrop of calcareous clays from beneath the Tehachapi



The fresh-water limestones of the Cable Formation, south of Cable.

alluvium. These clays are probably a portion of the fresh-water formation and if so, they indicate a northerly dip of the formation.

It thus appears that the Cable fresh-water beds lie in an asymmetric synclinal trough, the nose of which is situated below Cable at the point where the strike changes its course from northwest and southeast to north and south. An interesting fact indicating at once the former extent of the lake beds and the nature of the deformation to which they have been subjected is the occurrence, on a spur of the mountains to the north of Tehachapi, at a point about 2 miles north of the station, of an outlying patch of cherts plastered as it were on the face of the mountain slope, the dip of the beds determining the angle of declivity. The projection of these beds to the northeast would carry them over the entire southerly slope of the mountains on this side of the valley.

Tehachapi Formation.—In the trough above indicated lies a great body of coarse alluvium, the Tehachapi Formation, reposing upon the Cable fresh-water beds and having approximately the same areal distribution as those beds. It is well exposed in many steep slopes and railway cuttings in the cañon of Tehachapi Creek above Cable. In these exposures it is seen to be composed of a coarse aggregation of rock fragments such as is usually found near the apex of the alluvial cone of a steep-grade stream. These rock fragments are in a fresh undecomposed condition and are but slightly cemented together so that separate blocks may be detached from the aggregate with ease. These materials comprise, not only granite rocks, schists, limestone and quartz of the Bed-rock Complex, but in certain portions of it there are numerous blocks of the Tank Andesite. In the lower part of the formation where it rests upon the uppermost beds of the Cable formation, the rock fragments are comparatively small, masses the size of a fist and less predominating and there is a considerable admixture of sand. Here the material is rudely stratified and where the contact is exposed in the railway cuts above Cable the dip of this stratification is the same as that of the underlying lake beds, about 12° to the southwest. In the higher parts of the formation the angular blocks of which it is composed are much larger in size and in the highest portions spauls of rock 10 feet in diameter are occasionally met with while masses from 3 to 5 feet in diameter are quite common. In general, stratification is not apparent throughout the formation even in excellent exposures except at its base, as above mentioned, and it is difficult to estimate its thickness. Some idea of its volume may be obtained, however, from the fact that the highest part of the formation is 350 feet above the level floor of the valley at Tehachapi Station and assuming a gentle syncline for the structure of the formation as a whole this figure may be taken as a value for its thickness.

This thick accumulation of coarse alluvium is the record of an important event in the diastrophic history of the southern Sierra Nevada. It is considered by the writer to have been, anterior to its deformation and degradation, a great cone such as is found commonly where high grade streams emerge from narrow mountain cañons and spread out abruptly upon a lower grade valley. Their situation is always along lines of geomorphic discordance, or where the geomorphic features of the mountain are completely out of harmony with those of the adjacent valley from the point of view of erosional evolution. Such situations are produced by faulting or by other acute deformation of the region, whereby the mountain mass has been uplifted relatively to the valley. Occasionally a trunk stream may flow in a cañon which has been overdeepened relatively to its tributaries and the conditions may in such cases be favorable for the development of alluvial cones at the mouths of the hanging valleys. These conditions, however, are most commonly found in glaciated regions, and even then the geomorphic discordance between the overdeepened cañon and the tributary hanging valley is slight compared with that which obtains between the recently uplifted mountain ranges and the broad diastrophic valleys which parallel them in Southern California and in Nevada.

On the assumption which is here made of the strictly fluviatile origin of the Tehachapi formation it is evident that an acute deformation of the region occurred at the close of the Cable lacustral period, and caused a rapid dejection of coarse mountain detritus into the basin formerly occupied by the lake from country where no high grade streams had previously existed. It is noteworthy, moreover, that the position of this coarse alluvial material, in the northwest corner of the present Tehachapi Valley, establishes the fact that its source was in the mountains to the south. In other words, it is clear that at the time of the accumulation of this great alluvial cone *the drainage was from the north,* and was approximately, in part, along the line of the present deep cañon of Tehachapi Creek which flows from south to north. The present drainage then, to the Great Valley of California has a direction which is the reverse of that which formerly obtained along the same general course. This fact is one of prime significance in any attempt to explain the present dual outlet of Tehachapi Valley.

But while it is clear that orogenic movements inaugurated the accumulation of the great cone, it is no less clear that orogenic movements subsequent to its upbuilding have deformed it. What is left to-day of the great cone is but a remnant of its original mass and extent. It now lies in a synclinal trough. Whenever its base is exposed it reposes upon the Cable lake beds and the rude stratification of the lower part of the formation where exposed above Cable Station is parallel to that of the lake beds. It probably nowhere extends at present beyond the rim of the synclinal trough formed by the lake beds. It certainly does not in the numerous and often persistent exposures where the two are seen in juxtaposition. The lake beds are nowhere horizontal but dip in all observed cases for several miles of outcrop on different sides of the trough under the alluvium, and on the west side of the trough they are well exposed in one locality in a perfectly vertical attitude. It is evident then that the whole body of the alluvium has been subjected to the same measure of deformation as that which can be made out clearly from the attitude of the underlying regularly stratified lake beds.

Planation.—Since its deformation the Tehachapi alluvium has been broadly terraced by stream action, the terrace has since been deeply dissected and the mass has otherwise been degraded by the forces of erosion. The broad terrace which truncates a large proportion of the total area of the formation is a most interesting feature of the geomorphy of the region. The terrace is not confined to the alluvial formation, but extends, as a broad even plain, indifferently across the alluvium, the soft beds and hard cherts of the Cable formation, and the schists, limestones and granite of the Bed-rock Complex. The terrace slopes down to the south at a low angle. Its expanse increases also in this direction and it eventually passes beneath the present floor of Tehachapi Valley where it meets the opposite slope of the China Hill alluvial fan. The terrace becomes constricted to the north, and leaving the valley it passes into the mountains, which lie on this side of the valley, in the form of bench-like remnants high up on the eastern slope of Tehachapi cañon. Just before passing into the mountains north of Cable, it is bounded on the west for a short distance by a sharp residual ridge of the Tehachapi alluvium. Beyond the south end of this ridge, however, the terrace extends over to the steep, rocky mountain slope which forms the western boundary of the valley. On the east side of the railway above Cable, the stream which carved the terrace, in the course of its meandering and lateral corrasion, cut an embayment over a mile in breadth out of the main mass of the Tehachapi Alluvium. This embayment is bounded on the east and south by a relatively high semicircular residual ridge of the alluvium. This semicircular ridge, together with the similar residual ridge on the west side of the railway nearer Cable, are so disposed as to give these prominent residuals of the Tehachapi alluvium the configuration of a terminal moraine. This superficial resemblance to a moraine is enhanced by the numerous spauls of rock of considerable size which weather out of the alluvium and lie strewn over its surface. The facts above cited prove, however, that the resemblance to a moraine is quite superficial and accidental as regards at least its form.*

It has been pointed out that the source of the materials for the Tehachapi Alluvium was probably in the mountains to the

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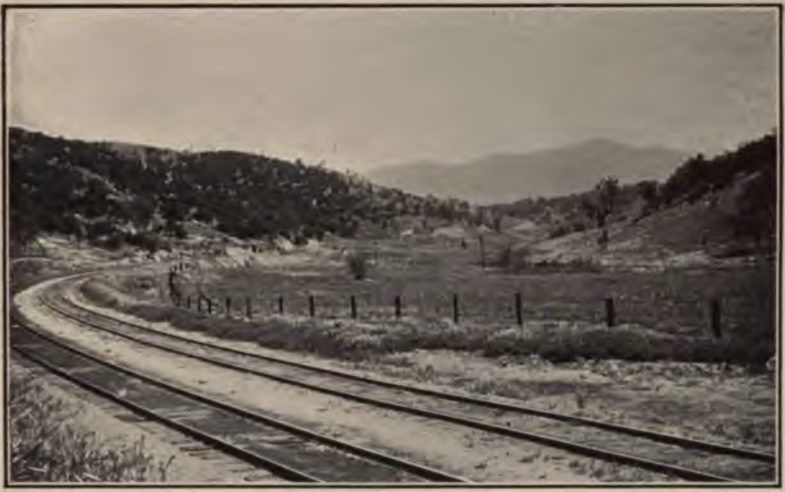
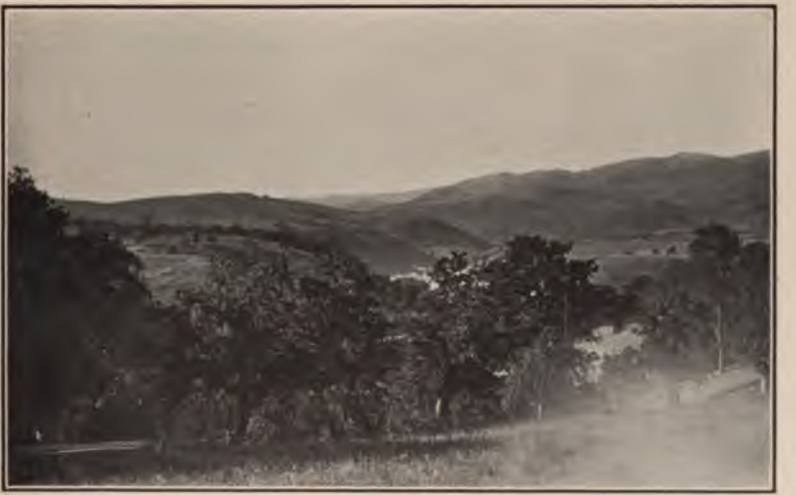
* It is to be observed that on the basis of its composition alone there might be considerable doubt as to whether the Tehachapi formation were fluviatile or glacial in origin. But as the mountains of the region do not exceed 7000 feet in altitude, and present no traces of glacial sculpture, and as the material rests on a non-glaciated surface and is in part stratified, the writer was forced to reject the glacial hypothesis and interpret the accumulation as an alluvial cone.



A. Tehachapi Creek as it leaves Tehachapi Valley near Cable, showing the degree of dissection of the terrace shown in Plate 46.



B. Stream terrace near Cable on the sides of the cañon of Tehachapi Creek. The terrace slopes *up* to the north, the direction of the present drainage.

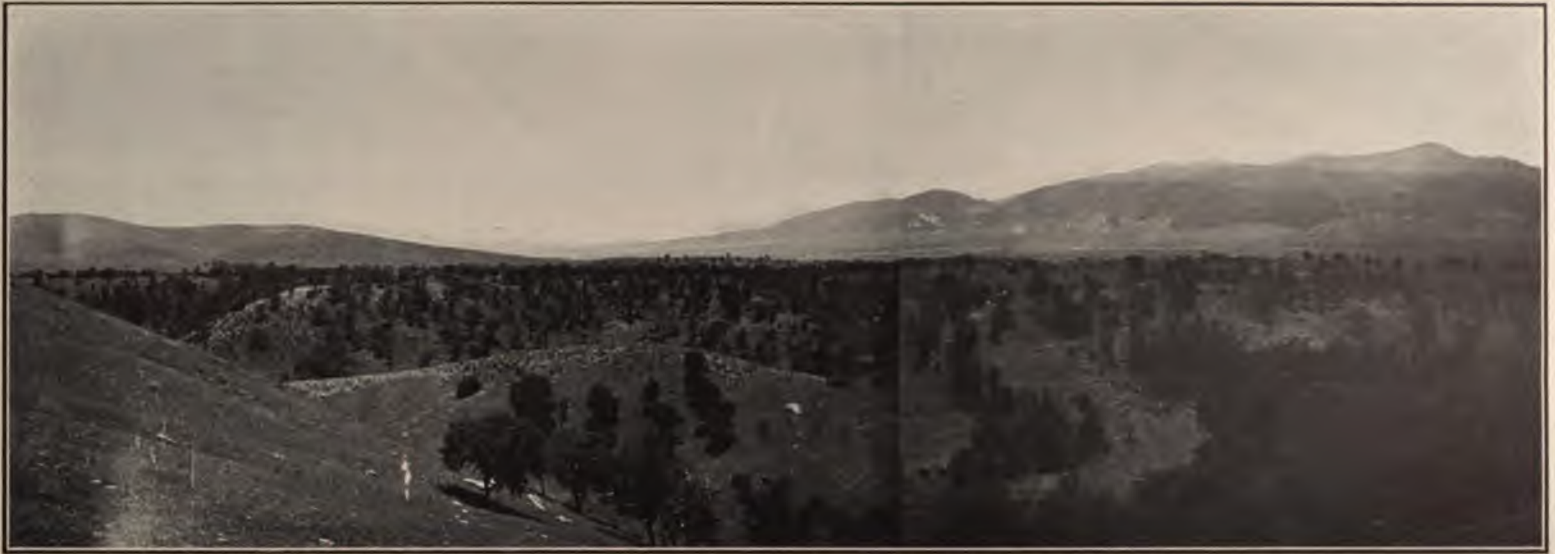
north of the present Tehachapi Valley, these materials having been brought to the seat of deposition by a high grade stream engaged in the rapid dissection of a recently uplifted mountain block. It has been shown further that the later orogenic movement which deformed the Tehachapi Alluvium was characterized by a recurrence of the uplift on the north side of the present Tehachapi Valley. The stream which gave rise to the Tehachapi Alluvium would, by this second uplift, have had the grade, to which it had attained, again accentuated. This accentuation of grade would apply now to the country occupied by the alluvial cone and the latter would consequently be dissected. The dissection of the cone would continue till a grade profile was established, when the stream would begin to meander and evolve an ever-widening flood-plain on a stream-cut terrace. This terrace would be cut out of the alluvium and the rocks adjacent to it or under it indifferently. The history thus sketched appears to be that of the broad stream terrace which has been described as traversing the Tehachapi Alluvium, the Cable lake beds, and the various rocks of the Bed-rock Complex above Cable.

If this interpretation be correct, then it is clear that the drainage, at the time that the terrace was functional as a flood-plain, was *from* the north and not *towards* the north as at present.

Dissection and Reversal of Drainage.—Since its completion the terrace has been deeply dissected and this dissection has been effected by a northerly flowing stream, the present Tehachapi Creek which drains into the Great Valley. In the vicinity of Cable this dissection amounts to 350 feet or more; and in the tributary creek, which comes in from the left from China Hill, and which joins Tehachapi Creek about half a mile above Cable, cutting through granite, schist, limestone, Cable lake beds and Tehachapi Alluvium, the dissection is about 250 feet in depth. The valley of this stream where it cuts through the hard rocks has a width of about 150 feet and in the soft rocks of over 300 feet on its bottom.

Two circumstances seem to have conspired to bring about the reversal of the drainage above indicated. It has been shown that the terrace surface slopes to the south and passes beneath the modern alluvium of Tehachapi Valley, or, more particularly, beneath the alluvium of the China Hill cone. What its extent may be beneath this alluvium is unknown but it is clear that the accumulation of this alluvium upon the southern extension of the flood-plain would tend to pound back the waters coming from the north and cause them to seek another outlet if such were available.

Such an outlet was provided by the headwater erosion of a stream on the Great Valley side of the mountains. The two orogenic movements which have been recorded as affecting the mountains in this direction greatly accentuated the grade of the streams on the north side of the divide, and one of these, the present Tehachapi Creek, caused the divide to migrate southerly till it reached the terrace of the southerly flowing stream, and not only effected its capture but provided an outlet for its beheaded portion, the waters of which, in greatly diminished volume, were obstructed by the excessive accumulation of alluvium upon its flood-plain. The question now arises as to the cause of this excessive accumulation of alluvium. The answer to this question is very pointedly suggested by a consideration of the geomorphic features of the region which is the source of that alluvium. The alluvium all comes from a few sharp, torrential cañons which emerge, above grade, upon Tehachapi Valley, from the straight, bold wall of Tehachapi mountain which forms the western half of the southern boundary of the valley. The geomorphic discordance which these cañons present to the broad, alluviated Tehachapi Valley is in itself ample proof of the fact that the mountain mass which they dissect is a fault block. The northern slope of the mountain is steep and on the whole not greatly degraded. This face has a regular east and west trend, transverse to the strike of the schists and limestones which together with granitic rocks make up its mass. The cañons which discharge the alluvium are relatively so insignificant that they do not greatly notch the longitudinal profile of the mountain and their mouths can scarcely be perceived at a distance of a few miles. If such evidence that the face of the mountain is a degraded fault scarp were not sufficient, more direct evidence may be observed at the point where Antelope



Dissected stream-cut terrace at the northwest corner of Tehachapi Valley sloping down *from* the outlet to the valley floor.

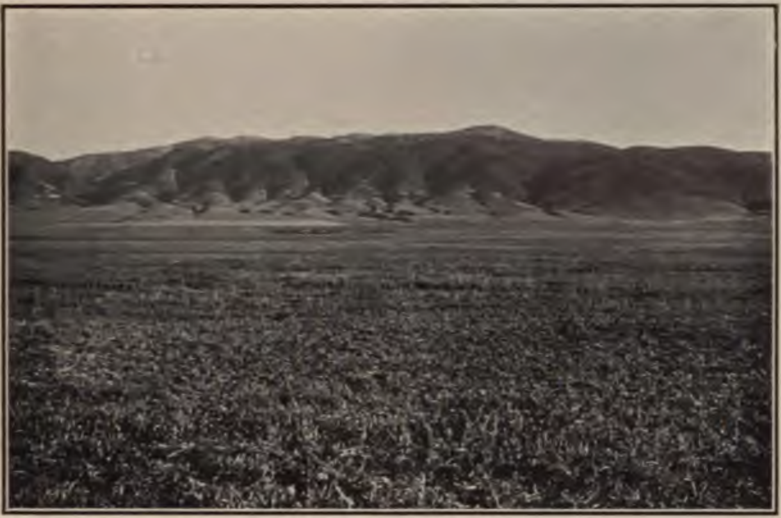
Creek emerges upon the valley. Here it is apparent that the apex of the alluvial cone which spreads out from this point across the entire breadth of Tehachapi Valley was established when the rock bottom of the creek within the mountain was much higher than it is at present. The cañon bottom has been corraded down to a depth of 250 feet below the apex of the cone and this deepening of the rocky cañon has necessitated the dissection of the higher part of the alluvial cone. There is thus exposed in the walls of the cañon the contact betwen the buried face of the mountain and the alluvium which reposes against it through a vertical range of 250 feet. This contact, while not absolutely vertical, is so nearly so that the rock surface against which the alluvium rests can be interpreted only as a fault scarp. That is to say, it is the lower portion of the general fault scarp of the mountain front which has been preserved by burial from the greater part of the degradation which has affected the upper portion.

In the recognition of the fault scarp nature of this mountain front we have evidence of a third orogenic movement, and its discreteness in time from the other two movements, which have been recorded as affecting particularly the north side of the present valley, is proved by the fact that the alluvial debris which was produced by the torrential corrasion of the uplifted block, was dejected upon the broad terrace which had been in part cut out of the deformed Tehachapi Alluvium.

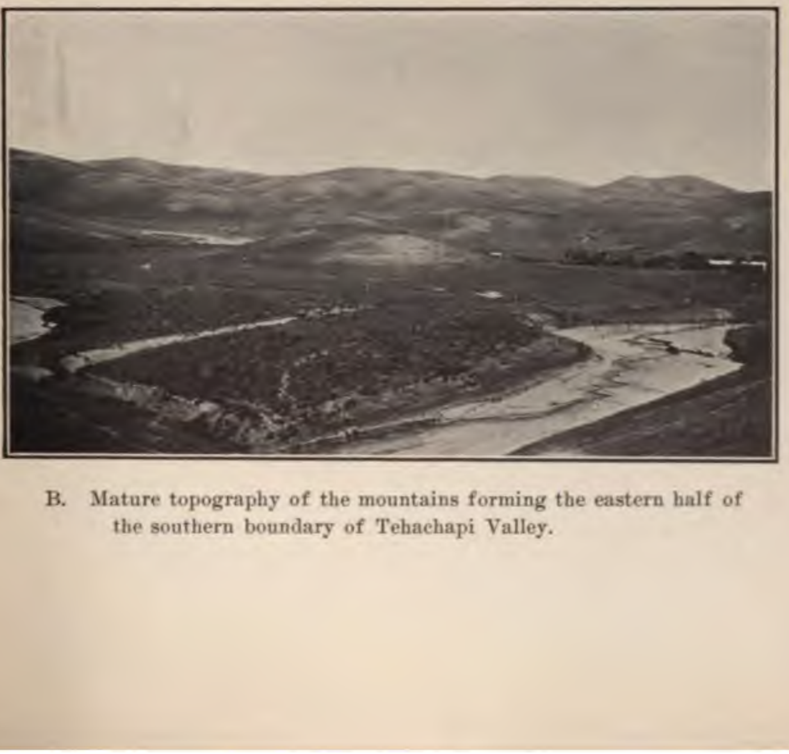
Mature Geomorphy.—If now we continue our consideration of the south boundary of Tehachapi Valley into its more eastern part beyond the portion which has just been identified as a fault scarp, we come upon a totally different type of geomorphic expression. Here the valley is bounded on the south by a range of hills of gently flowing profiles and contours. The hill tops are flatly rounded and there are no incisive cañons dissecting them. The slope to Tehachapi Valley is not steep and abrupt but descends as an undulating surface, on the lower parts of which there are remnants of stream terraces strewn with well washed cobbles and pebbles. The height of these hills is probably about 1000 feet above Tehachapi Valley or less than half the height of the fault block mountain immediately to the west of it. The edge of these mature hills where they meet the floor of Tehachapi Valley is not a straight line, as is the case with the fault scarp to the west, but is more or less indentate and on the whole sinuous or concave to the north. It is evident from the facts cited that we have here to deal with a quite mature geomorphy which has been entirely unaffected by the dislocation upon which the fault block to the west was uplifted. When first viewed from a distance the contrast between these two portions of the south boundary of Tehachapi Valley was so striking that the writer supposed that the underlying rocks must be totally different. But an inspection of the ground showed that this was not the case. The rocks which underlie the geomorphically mature hills to the east have the same granitic character as those which form the bulk of the fault block mountain to the west with its bold, youthful features. It seems clear, then, that the fault scarp does not extend eastward beyond the dividing line between these two contrasted types of geomorphy. It follows from this that the dividing line between the fault block mountain and the unfaulted, mature hills immediately to the east of it is a transverse or north and south fault, and that the fault block is tilted to the west as well as to the south.

Such a mature geomorphy as has been above indicated is evidently but a remnant of what was once the general condition of the region, and as this mature surface passes down beneath the floor of Tehachapi Valley, it is probable that we have beneath this part of the valley an earlier mature valley of erosion quite different in its configuration from the modern feature. Towards the eastern outlet of Tehachapi Valley, the north and south sides of the valley converge and here the edge of the mature hills is quite abrupt, but their acclivity appears to be that of a stream cliff of a stream no longer functional, whose rocky bed is deeply buried in the alluvium from Cache Creek.

Western Boundary of Valley.—There remains to be noted the western boundary of the valley. This is a steep mountain slope of very even and but feebly notched front, except for the gap into Brites Valley. This as will appear later is the revetment end of a rather narrow fault block and as such has but little water to discharge to Tehachapi Valley and so has been



A. Degraded fault-scarp forming the western half of the southern boundary of Tehachapi Valley.



B. Mature topography of the mountains forming the eastern half of the southern boundary of Tehachapi Valley.

but slightly affected by stream erosion. It can scarcely be regarded as other than a somewhat degraded fault scarp. The date of its origin is, however, not quite clear. It appears to have antedated the broad terrace which lies at its foot, and may with much probability be referred to the period of orogenic movement which deformed the Cable Lake beds and the Tehachapi Alluvium, since the western edge of the trough in which these formations lie is parallel to its trend and the trough on this side is most acutely deformed so that, as before stated, the Cable Lake beds and the plane of contact between them and the overlying alluvium are in vertical altitude. It is probable, however, as will appear in the sequel, that a second movement of minor extent took place on this same fault at a later date.

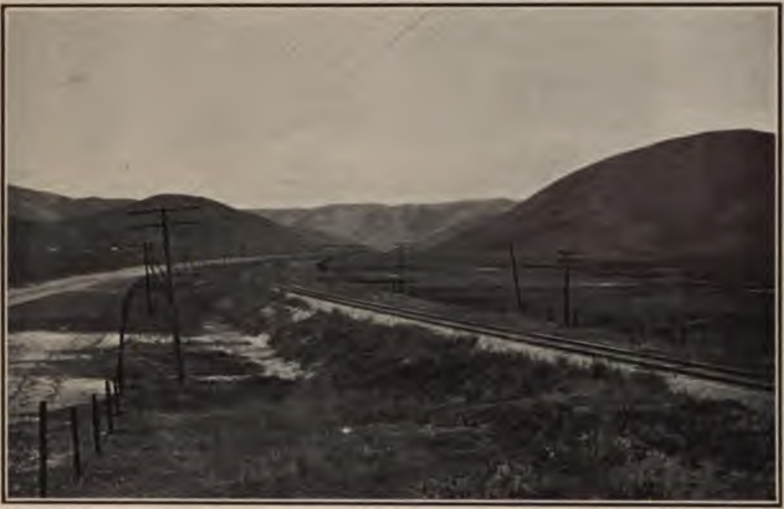
GEOLOGICAL HISTORY.

Reviewing now the data that have been presented, the history of the evolution of Tehachapi Valley in so far as the writer has been able to decipher it, in the limited opportunities at his disposal, may be summarily stated. It is not presumed that the statement is complete. When the region is mapped and its features are more closely studied it will doubtless be amplified, and perhaps in some respects modified.

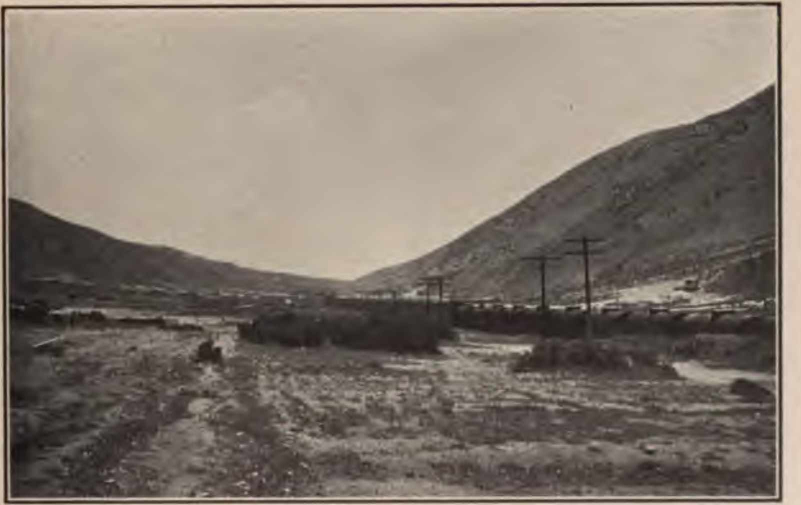
After the profound degradation of the mountain mass which resulted at the time of the mid-Mesozoic revolution in consequence of the invasion of the region by the Sierran batholith, a basin of deposition was developed in which accumulated the sandstones, conglomerates and shales of Cache Valley, and the tuffs and agglomerates of White Rock Valley. The basin was probably lacustrine in character and is probably to be correlated with early Tertiary lake basins of other portions of the Great Basin. These lake beds and tuffs were folded, but not closely appressed, and were then largely removed by erosion, the bed-rock surface upon which they were deposited being in this way in large measure resurrected and subjected to renewed degradation. The next event of which we have note is an orogenic disturbance of the region and the formation of diastrophic valleys bordered by abrupt mountain fronts. This event is an inference based on the occurrence of a coarse alluvium. Alluvium of this character is only known as the product of torrential streams emerging from narrow high grade cañons upon broad open valleys. Such valleys are geomorphically discordant with the erosional features of the mountains whence the streams emerge, and such discordance can usually only be explained as due to diastrophic movements. This accumulation of coarse alluvium was followed by an outburst of volcanic activity, which gave rise to showers of ashes and scoriae and a flow of andesitic lava. Upon the new surface configuration of the region thus established, a lake basin, or possibly several of them, interrupted the normal course of the drainage. In this basin there accumulated the Cable formation consisting of limestones in which fresh water molluscs were entombed, beds of clay, more or less calcareous, and, in the vicinity of incoming streams, beds of gravel and sand. Interstratified with these lacustral beds is an abundance of volcanic tuff also for the most part well stratified. These probably represent the recurrence of volcanic eruptions during the lacustral period, although they may also in large part at least, be explained as the product of the erosion of the surrounding ash mantled country.

This lacustral condition was brought to a close by another orogenic movement which uplifted the mountains to the north of the valley in which the lake lay. The lake was displaced and its deposits were buried under a vast accumulation of coarse alluvium, the Tehachapi Formation, evidently the cone of a torrential stream actively engaged in the dissection of the new mountain mass. The source of the alluvium was from the north.

The next event of which we have record is another orogenic movement which deformed the region both by flexure and faulting. At this time the pre-Cable volcanics, the Cable Lake beds, and the Tehachapi alluvium, or at least so much of these formations as are left for our inspection, were together folded in an asymmetric syncline, the most acute deformation occurring on the west side of the trough where the beds are now vertical. At this time the fault scarp which forms the boundary of Tehachapi Valley on the west was also probably formed. This period of acute deformation was succeeded by a period of vertical stream corrasion till the streams attained their base level and then began to evolve a broad flood plain by lateral corrasion. This flood



A. The eastern end of Tehachapi Valley, looking southeast toward the eastern outlet at Cameron.



B. Looking down the eastern outlet of Tehachapi Valley toward Mohave Desert from Cameron.

plain was developed as a very notable feature of the region, being cut across hard and soft rocks alike with great evenness. It is very probable from our general notions of the conditions which attend the evolution of stream-cut plains, that this flood plain stood at a much lower level than its remnants do to-day (4000 feet A. S.). It marks an important datum plane in the evolution of the Sierra Nevada and is the probable correlative of the high valleys of the Upper Kern.*

Up to this time there was probably no such feature as the modern Tehachapi Valley. But now the process of flood plain expansion was abruptly terminated by another orogenic movement, which besides effecting a general elevation of the region far above the base level of the streams, also raised Tehachapi Mountain as a fault block on the south of the present valley and gave the latter its modern configuration as regards its boundaries. The uplift of this block caused the dejection upon the flood plain of the alluvium which forms the greater part of the floor of the valley. Co-eval with this progressive obstruction of the drainage on the flood plain, the head waters of its stream were captured by head water erosion cutting back from the Great Valley into the upraised mountains. The beheaded stream was unable to cope with deluge of torrential debris from the new mountain mass on the south and its course was reversed into the same stream that had captured its head waters. Since this reversal of the drainage the flood plain has been dissected.

The geological history of the eastern outlet of Tehachapi Valley is not so complex. The outlet is a rocky gorge so deeply alluviated as to give a rather broad bottom (200 yards). If we imagine the alluvium removed below the depth of certain wells that have been sunk in it but have not bottomed it, and suppose the rocky slopes projected down we would have a quite narrow and somewhat tortuous mountain gorge. This character establishes the fact that it was not the outlet for the stream that corroded the broad terrace at the western end of the valley. The gorge, *with its present direction of drainage,* could not very well have been evolved *after* the present boundaries of Tehachapi Valley were established. It must, therefore, antedate the modern Tehachapi Valley, *i.e.*, it must antedate the fault block which forms the south boundary of the western half of the valley. This being so the gorge must have been coexistent with the stream which evolved the broad terrace at the west end of the valley, and if this be conceded then the gorge was that of a small eastern affluent of the larger stream. From this line of reasoning we thus reach the conclusion that the drainage of this outlet was also at one time toward the area of the present Tehachapi Valley and that this drainage has been reversed. The causes of the reversal are doubtless two-fold. The uplift which terminated the process of flood plain expansion in this region was without doubt effected by a movement on the great fault which bounds the Sierra Nevada on the east and southeast and which here separates them from the Mohave desert. Such a movement would have beheaded this gorge and have rendered it an easy matter for the rapidly accumulating alluvium in the now mountain-girt Tehachapi Valley to congest the gorge and cause the waters to flow out to Mohave.

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* Geomorphogeny of the Upper Kern Basin, Bull. Dept. Geol. Univ. Cal., Vol. 3, No. 15.

It thus appears that both of the outlets of Tehachapi Valley antedate the valley as we know it to-day, and that they are both cases of reversed drainage brought about by orogenic movements, inducing stream capture and the obstruction of the beheaded streams by great alluvial cones.

BRITES VALLEY.

Brites Valley opens into Tehachapi Valley at the southwest corner of the latter through a gap between the fault scarp which bounds both valleys on the south and the northeast corner of Bear Mountain. The trend of the valley is northwest and southeast, in which direction it has an extent of 3½ miles. Its breadth is about 1¼ miles. Its southern boundary is the western extension of the same degraded fault scarp as that which bounds Tehachapi on the south. Its northeastern boundary is a mountain wall with a very straight trend and a steep, even, little notched slope, which can only be interpreted as a fault scarp, The bearing of this scarp is northwest and southeast, thus making an angle of about 45° with the strike of the rocks. It may be referred to as the southwest scarp of Bear Mountain. The western boundary of the valley is a sharp low ridge with north and south trend which spans the space betwen the two converging scarps above noted. This ridge is composed largely of crystalline schists, the strike of which is north and south with the trend of the ridge. The ridge separates Brites Valley from a larger valley on the west known as Cummings Valley, which lies at a much lower level. At the southeast end of the valley a mountain stream comes in from a gorge in the southern scarp. This stream has built up an alluvial fan which is co-extensive with the limits of the valley. The floor of the latter is the surface of this fan and its general slope is down toward the northwest end of the valley, where the outflowing waters have cut a gorge down through the edge of the fan and deep into the underlying bedrock, and so find their way to Cummings Valley. Along the base of the southwest scarp of Bear Mountain, the debris from the degradation of the scarp interdigitates with the edge of the fan and being locally dominant reverses the slope.

The gap through which one enters Brites Valley from Tehachapi is a platform of bedrock or flat-topped ridge between the two valleys. But over this ridge some of the alluvium from the fan which fills Brites Valley has spilled into Tehachapi Valley. A terrace-like shoulder on the south side of this flat-topped rocky barrier, where it is crossed by the wagon road is 544* feet above Tehachapi station. The lowest part of the gap is about 500 feet above Tehachapi station. The floor of Brites Valley at the farm house at its west side, just before entering upon the descent to Cummings Valley, is 446 feet above Tehachapi station. From these figures it will be apparent that Brites Valley is on quite a different level from Tehachapi Valley, a fact, which, considering their immediate juxtaposition and open connection, can only be explained on the hypothesis of their diastrophic origin. The eastern edge of the rocky platform which separates the valleys is in direct line with the western scarp of Bear Mountain and we have in this fact a pointed suggestion that Brites Valley has been dislocated from Tehachapi Valley by a movement on the fault which established this scarp. The gap which connects the two valleys over the rock platform is about half a mile wide, and the rock platform is with little doubt a surface of stream planation. This suggestion is confirmed by the section afforded by the gorge at the outlet of Brites Valley. Here the base of the alluvium may be seen reposing upon the bedrock surface, and that surface is again a platform which can only be regarded as a product of stream corrasion. It would seem, therefore, that, flanking the southwest scarp of Bear Mountain where it bounds Brites Valley, there is a stream terrace in large part buried by alluvium. It seems a fair hypothesis in the absence of any other suggestion to correlate this stream-cut terrace with the broad terrace already described as occurring in the northwestern portion of Tehachapi Valley; and in this hypothesis we have the farther suggestion that the stream, which evolved the now dislocated and partly buried terrace, flowed out westward through the present site of Brites Valley.

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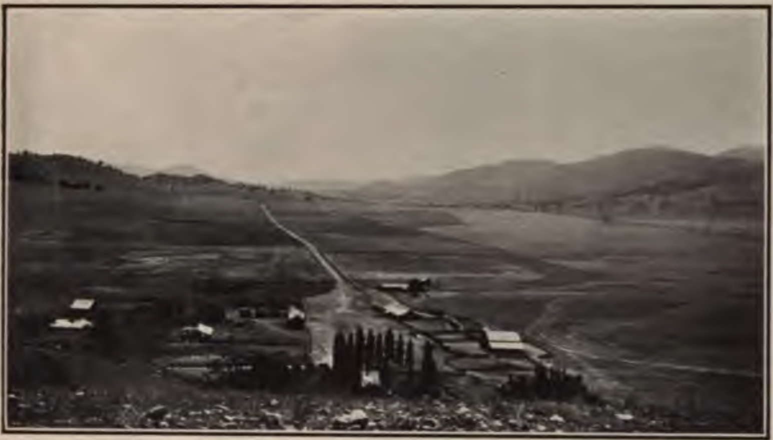
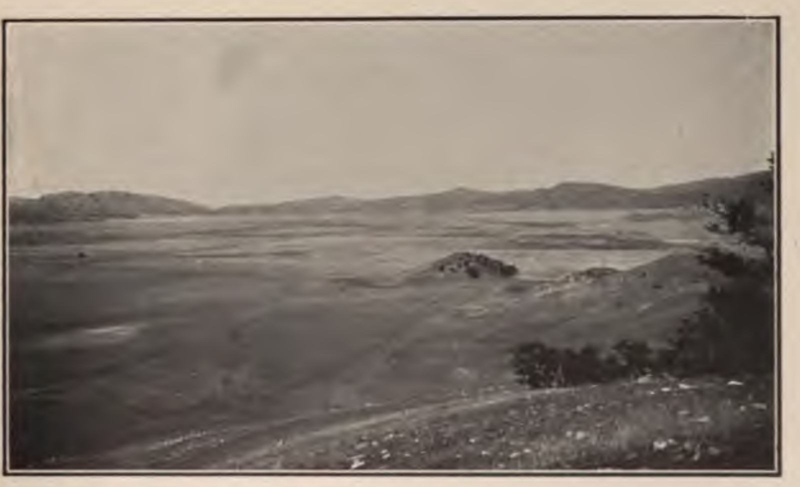
* This and other altitudes were determined, where not otherwise stated, by means of a mercurial barometer, using Tehachapi station, elevation 3963 feet, as a base.

CUMMINGS VALLEY.

Cummings Valley lies immediately to the west of the sharp north-south rocky ridge which forms the western boundary of Brites Valley. It lies at a much lower level than Brites Valley, the drop from the one valley to the other being rather precipitous. In the northeast part of the valley where the wagon road to Bear Valley leaves the main road through Cummings Valley, the altitude is 4056 feet, or 353 feet below the lowest part of Brites Valley, while in the middle of Cummings Valley the altitude is 3924 feet, or 485 feet below Brites Valley. The general contour of the valley is that of a trapezium. Its eastern boundary, as already indicated, trends north and south and has a length of about 4 miles. Its southern boundary is the same east-west, degraded fault scarp which bounds Tehachapi and Brites Valleys on the south. This side is also about 4 miles in length. On the northeast, the southwest scarp of Bear Mountain forms its boundary for about 2 miles. The fourth side of the valley is the more or less serrate edge of a mountainous tract which rises to several hundred feet above the level of the valley on the west. The trend of this boundary is north-northeast and its



A. Looking east across Brites Valley. Tehachapi Valley in the distance.

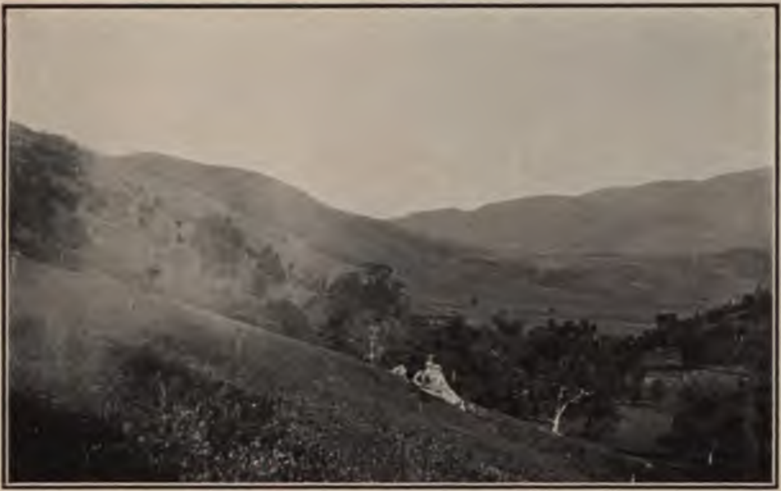


B. Looking southwest across Cummings Valley from near the outlet of Brites Valley.

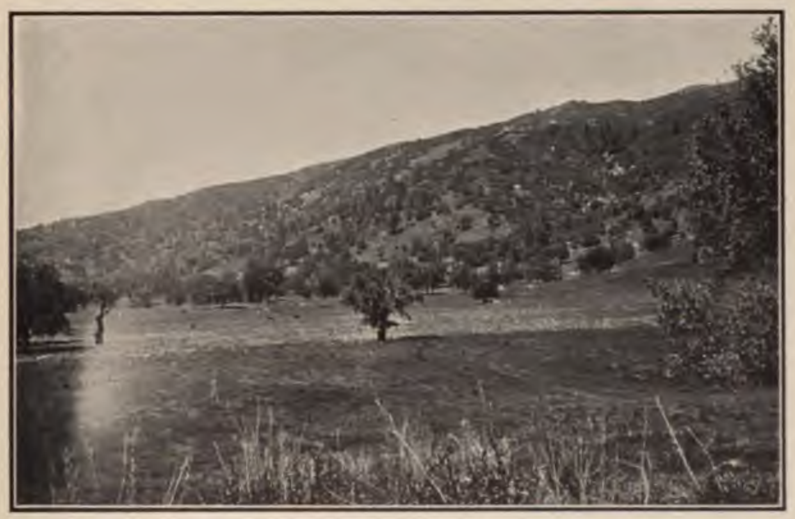
extent is 5½ miles. The valley thus bounded contains about 13 square miles. There are two principal lines of drainage through the valley. One of these is a stream that comes into the valley at its southeast corner from a high grade cañon in the mountain on the south. This stream has built up an extensive alluvial cone which spreads out over almost the entire valley. The drainage from Brites Valley skirts the northwest edge of this alluvial slope and catches part of the water that flows down the slope of the fan. The entire drainage of the valley converges on its southwest corner and after flowing for a short distance over a bedrock platform enters a narrow gorge and drops rapidly to the Tejon Valley. This gorge descends about 2500 feet in a distance of 4 miles. In the northern part of the valley this alluvial fan meets the waste slope from the southwest scarp of Bear Mountain, and it is the trough between these two opposing slopes which determines the path of the stream from Brites Valley for the first two miles of its course. Beyond this it is crowded over well toward the base of the hills on the northwest side of the valley. The valley thus largely occupied by alluvium is an artesian basin, and in the middle part of the valley a well has recently been sunk to a depth of 125 feet which yields a flow of water at the surface. The mouth of this well is but little above the rock platform over which the drainage flows before escaping from the valley. The well, therefore, proves that the valley, independently of the alluvium which fills it, is a rock rimmed basin. The rocky platform at the southwest corner of the valley is a most interesting feature. It extends out from the base of the hills which bound the valley on its northwest side a distance of half a mile and appears to pass under the feather edge of the alluvial fan with a uniformly flat slope, as is indicated by occasional protuberances of rock for some distance within the area of the alluvium. This platform is interpreted as a surface of stream abrasion and is correlated hypothetically with the similar stream-cut terraces above described, in Tehachapi and Brites Valleys. This platform probably extends as a flanking terrace, but thinly veneered with alluvium, along the greater part of the northwest side of the valley. The hills which rise above the valley on this side harmonize with this supposition. Although rocky slopes, they have a mature aspect, and the contour of the valley edge is indented with broad, wide-open embayments separated by narrow ridges or points of rock, the crests of which pitch down toward the valley and eventually pass beneath the alluvium. Frequently, off from the base of the hills, there are isolated knobs of rocks and rocky hillocks rising from the alluvium like islands. In general, then, the valley is bounded on this side by geomorphically mature slopes which pass down, a little below the present floor of the valley, into an uneven or lumpy terrace, which, however, is well exposed at the southwestern corner of the valley. There is thus no suggestion of faulting on this side. But such a terrace could not have been evolved with the present drainage scheme or the present configuration of the valley. It clearly antedates the valley. In its southern extension it abuts upon the fault block mountain to the south of the valley and it thus appears to have been cut off in the same way and at the same time as in the case of the stream-cut terrace of Tehachapi Valley, with which it is correlated.

The sudden drop from Brites Valley to Cummings Valley would seem to indicate with little question a fault along the eastern edge of the latter. In general it thus appears that on three sides Cummings is bounded by fault scarps and that as a result of the movements on these a geomorphically mature surface, including a stream-cut terrace, now situated at an altitude of between 4000 and 5000 feet above sea level, and immediately above the edge of the Great Valley, has been tilted down toward the southeast, so as to form a rock-rimmed trough, which has since been filled by alluvium, arising from the degradation of the fault block on the south.

This conception of the character of Cummings Valley involves the recognition of the fact that, before it became filled to its present level by alluvium, it must have been occupied by a lake. Should the central part of the valley, therefore, even be pierced by wells deep enough to reach its rocky floor it may confidently be predicted that such wells will pass through lake sediments. It is questionable whether this lake had an outlet or not. The present catchment area tributary to Cummings Valley is only about 45 square miles, or $3\frac{1}{2}$ times the area of the valley floor.



A. Fault-scarp forming the northeast boundary of Cummings and Brites Valleys. Ridge between the two valleys in the middle ground.



B. Main fault-scarp on the northeast side of Bear Valley, with alluviated fault-terrace in the foreground.

With this limited catchment and an annual rainfall of only 10½ inches it seems quite certain, under present climatic conditions, that the lake could not have attained the expanse necessary for it to reach the level of the lowest part of the rim of the basin. Assuming a run-off to the lake of 50 per cent. of the rainfall for a rocky region such as we have to deal with, and an evaporation of 60 inches per year under a more humid climate than now obtains, it would require a rainfall of at least 35 inches to enable the lake to attain the necessary expanse to escape at the present outlet. Such a rainfall is not an improbability for this end of the Sierra Nevada during glacial times. But it is to be noted that the present drainage outlet of the valley is through a gorge which has been cut down probably 300 feet since the enclosure of the basin by faulting. To attain this increased altitude for the original lowest place in the rim of the basin, the expanse of the lake would be considerably greater than the present area of the valley floor and the rainfall necessary to effect this would be correspondingly greater. A further objection to the lake ever having had an overflow at the original level of the outlet is that we should expect to find strand lines scored on the sides of the valley well above its present floor and no such strand lines have been detected. It seems thus that we are not warranted in assuming that the lake which once occupied Cummings Valley ever had an outlet, and that the drainage outlet which now exists has been evolved without the aid of an overflow. The outlet is a gorge about 300 feet deep at the point where it leaves the valley. Here the geomorphically mature surface to the north of the gorge abuts upon the precipitous mountain scarp which bounds the valley on the south. Where these two surfaces meet there is an asymmetric notch in the mountain profile which constituted, at the formation of the valley, the lowest part of its rim. This notch lay in the line of the fault scarp and could not be missed by a stream cutting back into the very precipitous mountain slope which rises from the Great Valley only a few miles distant. Cummings Valley has been tapped, then, by the headwater erosion of a tributary of Tejon Creek cutting back in a structural trough. A consequence of this conclusion is that the great mountain wall which confines the south end of the Great Valley on the east, between Caliente and the Tejon Ranch House, is itself a fault scarp, and dates from about the same time as the faulting which gave rise to Tehachapi, Brites and Cummings Valleys.

BEAR VALLEY.

Bear Valley lies to the northwest of Cummings Valley along the base of the southwest scarp of Bear Mountain. Its longer diameter is parallel to the line of the scarp and is about 3 miles in extent. The general width of the valley is about 2 miles. Its area is about 6 square miles. The valley is in two levels. Along the immediate base of the southwest scarp of Bear Mountain is a well defined terrace about 1000 feet wide mantled by the alluvial wash from the scarp which rises steeply at its rear This terrace is bounded on the southwest by a rather sharp rocky ridge which is in general less than 100 feet above the terrace, and which is notched down to the level of the terrace in a number of places. On the southwest side of this ridge there is an abrupt drop to the level of the main floor of the valley. The latter has an altitude of about 4300 feet at the Fickert ranch house. The terrace is from 300 to 500 feet above this, its highest point being at its southwest end where the wagon road from Bear Valley begins to descend to Cummings Valley. From this culminating point the terrace slopes down to the northwest in the direction of its extension. It is evident that this remarkable feature is a fault terrace. It is a narrow strip of the mountain mass lying between the main fault of the Bear Mountain scarp and a subsidiary parallel fault, the scarp of which forms the descent from the terrace to the main valley. The terrace probably sloped originally down toward the main Bear Mountain scarp and owed that slope to rotation of the fault-bounded block. The trough thus formed has since been filled by the debris shed from the scarp above. In its essential features this narrow fault block flanking a major fault scarp is identical with the kernbuts* of the Upper Kern. The main portion of the valley below the fault terrace is constricted near its middle by a narrow sharp ridge of small height which projects as a spur from the moun-

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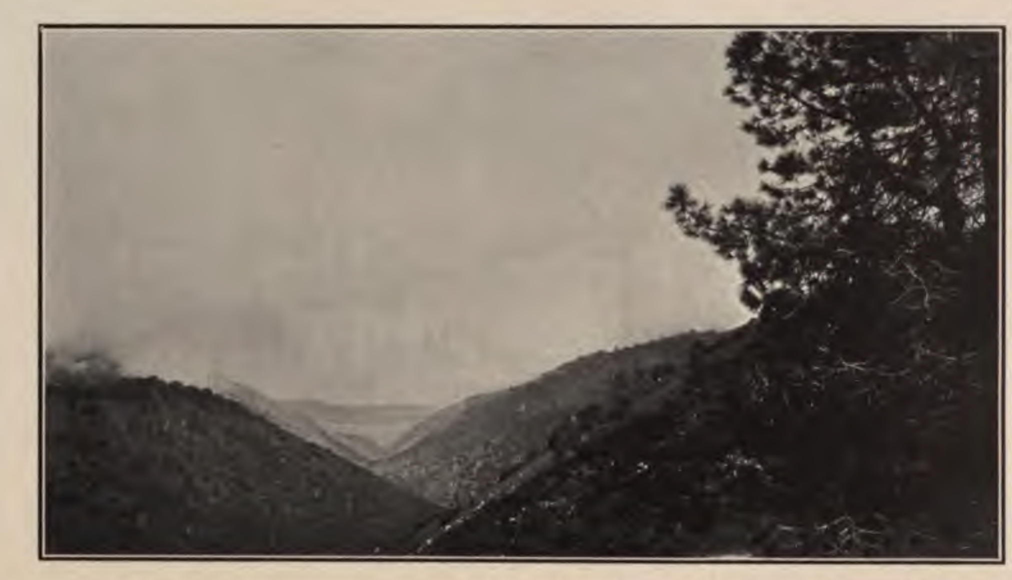
* Geomorphogeny of the Upper Kern Basin. Bull. Dept. Geol. Univ. Cal., Vol. 3, No. 15, p. 331.



Looking down Sycamore Creek from the outlet of Bear Valley to the Tejon Plains.

tain slope on the south, part way across the valley. The geomorphy of this side of the valley is that due to the normal process of erosion and presents no suggestion of faulting. The edge of the valley is indented and the slopes above it are mature.

No stream of importance comes into Bear Valley so that no notable alluvial cone occurs in it as in the other neighboring valleys. But the various streamlets and the general wash from the surrounding mountain slopes have contributed to its infilling and have given it a floor of alluvium except at its west end near its outlet by way of Sycamore Creek to the Great Valley. Here the alluvium which forms the floor of the valley feathers out and there is exposed a rock platform which is the counterpart of that already described near the southwest corner of Cummings Valley. This rock platform passes eastward and southeastward with an almost flat slope beneath the alluvium, and evidently underlies a considerable portion of the valley. It is with little question a remnant of the same system of stream-cut terraces, relics of which have been detected in Tehachapi, Brites, and Cummings Valleys. Its original relation to those relics is not clear, but that is not surprising in a region of such acute diastrophic deformation as that with which we have here to deal. In general, then, Bear Valley may be briefly stated to have originated by the downward tilting of a tract of mature geomorphy on the south, including a stream-cut flood plain, against a dominant fault along the southwest scarp of Bear Mountain; and that against this fault there was left in the down plunge a slab, or kernbut, which failed to drop as far as the rest and the top of which forms the ridge-bordered terrace on this side of the valley. valley.

Beyond this rock platform a narrow gorge opens in the mountain ridge which bounds the valley on the west and through this the waters of the valley find their escape by a very precipitous descent to the Great Valley 3000 feet below and only 4 miles distant. This gorge in its upper part lies on the line of the subsidiary fault scarp and the same suggestion for its development is here made as for the gorge which drains Cummings Valley, *viz.*, that it is due to the headwater erosion of a high grade stream, Sycamore Creek, cutting back in the face of the northwest scarp of Bear Mountain and finding the notch formed by the subsidiary fault, which notch was originally lower, as it now is, than the analogous notch made by the main southwest fault of Bear Mountain. Prior to the capture of the valley by Sycamore Creek it must have been occupied by a lake, since it is entirely rock rimmed, but the hydrographic basin which includes the valley is so small relatively to the area of the valley, that it is quite improbable that the lake had an outlet by rising to the level of the notch which was afterward deepened by the headwater erosion of Sycamore Creek.

University of California,
March, 1906.

7 1910

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